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REPORT

EXPERIMENTAL DIGITAL STEREO SOUND WITH TERRESTRIAL TELEVISION: field-tests from Wenvoe, October, 1983

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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EXPERIMENTAL DIGITAL STEREO SOUND WITH TERRESTRIAL TELEVISION: FIELD-TESTS FROM WENVOE, OCTOBER, 1983

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Summary

An experimental digital system to carry two high-quality sound channels with the existing terrestrial television transmission System I has been devised. This experimental system uses a 4-phase d.p.s.k. modulated second sound carrier spaced at about 6.55 MHz above the vision carrier and at a level of 20 dB below it. Within the spectrum space available a data-rate of about 700 kbit/s can be provided, which is capable of carrying a stereo sound pair of signals, or two independent sound signals. The existing analogue f.m. sound carrier at 6 MHz above the vision carrier is retained to maintain compatibility with existing receivers, but is slightly reduced in level to 10 dB below the vision carrier in order to avoid picture patterning due to beats between the sound carriers.

Over-air field-tests of the experimental system were conducted out of normal programme hours from the BBC-2 transmitter at Wenvoe in South Wales and its associated rebroadcast relay stations. These tests established that the experimental system is acceptably rugged against impaired reception due to low field-strength, multipath, and ignition interference, or any of these impairments in combination. Preliminary indications suggest that the service area for satisfactory reception of the digital sound signals would be equal to or greater than the service area limits for satisfactory colour television reception. These over-air field-tests also showed that signals according to the experimental digital system could be transmitted from a main station, and would travel acceptably through chains of up to five tandem transposers without major re-engineering of these items.

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TABLE 1

Specification of the Experimental Digital Stereo Sound with Terrestrial Television System as tested from Wenvoe

Frequency of the Second Sound Carrier	=	6.55 MHz above the vision carrier
Level of the Second Sound Carrier	=	− 20 dB with respect to the peak vision carrier level
Modulation of the Second Sound Carrier	=	4-phase d.p.s.k.
Bit-rate (overall)	=	704 kbit/s
Overall bandwidth of the transmitted d.p.s.k. signal (to −30 dB points with respect to peak second sound carrier level)		≈ 700 kHz
Level of the Primary Sound Carrier	=	−10 dB with respect to the peak vision carrier level

It uses SI units in accordance with B.S. document PD 5686.

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1. Background

For many years there has been interest in the possibility of adding stereophonic sound to existing television services. A number of possible methods exist for the transmission and reception of the additional sound signal required for stereophonic operation and some of these are also suitable for the transmission of independent sound signals, such as may be required, for example, to provide a bi-lingual service. The possibilities investigated by the BBC include[1] :

1) Pilot-tone sound (as used for stereo radio broadcasting)[2].

2) FM-FM sound (as used in Japan)[3,4].

3) Two-carrier sound (as used on a limited basis in West Germany)[3,5,6,7,8].

4) Digital sound (as proposed for use in DBS television)[9].

Methods 1) and 2) are probably simplest to implement but do not have the necessary potential for high-fidelity stereo sound; they are both vulnerable to interference from co-channel stations and other effects, which can cause audible whistles and buzz. Furthermore, with both of these systems the available separation between the two sound channels can be insufficient for the transmission of two independent sound signals, as would be required, for example, for a bi-lingual service[3].

Method 3), a two-carrier sound system, appeared to be more promising. Such a system is in use on a limited basis in West Germany and a variant of that system, adapted to suit the UK System I broadcasts, has been investigated by BBC Research Department. Towards the end of 1982, over-air compatibility tests of this variant of the German two-carrier system were carried out using the BBC-2 transmitter at Crystal Palace outside normal programme hours[8]. These compatibility tests were observed by staff from the BBC, ITV and receiver manufacturers and some 414 questionnaires were completed and analysed. The results indicated that the proposed system would only be marginally compatible; in order to avoid patterning on the picture caused by beats between the sound carriers, it was found to be essential to reduce the level of the main sound carrier. But reducing the level of the main sound carrier to 13 dB below vision as in Germany, was found to increase the buzz-on-sound in some existing receivers.

During the period of testing these various options for an analogue stereo sound with television system, the status of digital techniques in domestic equipment had changed considerably. Thus we already have available as a consumer product the digital audio disc with its attendant very high quality sound. And we have the intention to use digitally coded sound for DBS television[10]. This leads to the consideration of the possible adoption of digitally coded sound for future use with terrestrial television. However, whereas in the case of DBS a digital sound signal with up to eight channels can be accommodated, due to a very limited spectrum space, it is unlikely that more than two channels could be accommodated by a digital signal added compatibly to an otherwise normal terrestrial television signal.

The addition of a digital sound signal involves the addition of a second sound carrier, as in the case of the German two-carrier system. However, in the case of a digital two-carrier system, the level of the second sound carrier can be much lower, and as the signal is more noise-like in nature any patterning due to beats between the main and secondary sound signals is thereby less visible on the picture. Because of the relatively low-level of the digitally modulated carrier, little, if any, reduction in the level of the main sound carrier should be needed, thereby avoiding the increased buzz-on-sound problem found with the analogue two-carrier system.

A thorough examination of the digital option was therefore commenced by Research Department and a preliminary experimental system was devised.

2. Choice of parameters for an experimental digital stereo sound with terrestrial television system

The outline parameters of the experimental digital stereo sound with terrestrial television system are summarised in Table 1.

2.1. Bit-rate and sound quality

Simple linear quantisation of an audio signal requires at least 13 or 14 bits per sample for acceptable broadcast quality. Neat-instantaneous digital companding[11], however, enables the number of bits per sample to be reduced to 10 with virtually no degradation in quality. For a 15 kHz audio-bandwidth, a sampling frequency of at least about 32 kHz is required. Thus, the minimum bit-rate for a single-high-quality audio-channel is about 320 kbit/s, to which must be added the bit-rate needed to transmit overheads such as framing words, parity bits, and the scale-factor words for the near-instantaneous companding.

In previous BBC experimental work concerning the transmission of high-quality digital sound signals[12], a bit-rate of 704 kbit/s was adopted for two high-quality digitally coded sound channels. This bit-rate is conveniently an integral multiple (x 22) of the sampling frequency, 32 kHz, which leads to some simplification in the decoder and is sufficiently greater than the bare minimum capacity of 640 kbit/s as to provide a few kbit/s of spare data capacity for supplementary control signals. It was therefore decided to adopt 704 kbit/s as the bit-rate in this present work.

The quality of sound offered by such a digital system would be comparable to that provided by the digital point-to-point links which are used within the BBC for the high-quality distribution of sound signals throughout the United Kingdom for both radio and television broadcasting. This quality does not quite match the potential quality of digital audio disc, which has a slightly greater audio bandwidth (20 kHz instead of 15 kHz) and slightly better dynamic range (16 bits as against 14 bits). In practice, however, under domestic listening conditions, the perceived quality of the digital system proposed here is expected to be comparable with that of the digital audio disc.

2.2. Choice of digital modulation techniques

In choosing a modulation technique for any digital transmission system, a compromise must be sought between:

1) Bandwidth required.

2) Signal-to-noise ratio required to achieve a given minimum bit error-rate. This usually determines the carrier power required.

3) Cost. As in any broadcast system, it is highly desirable to minimise the cost of the decoder in domestic receivers.

After considering the above, it was clear that the broad family of 4-phase phase-shift-keying (p.s.k.) systems (in which, during each symbol interval, one of four possible phase-states conveys two bits of information) offered the best compromise between the requirements of bandwidth, carrier power, and cost. Indeed, this family of systems is widely favoured for digital transmission in many other fields[13].

The detailed choice of a system within this broad family of 4-phase p.s.k. systems (under which heading we include 4-phase offset differential p.s.k., minimum-shift-keying (m.s.k.) [14,15], etc) was more difficult, and indeed the choice for the present application is still the subject of further study at the time of writing this report. However, earlier work in other contexts [16,17,18], had already given us considerable experience with 4-phase differential-phase-shift-keying (4-phase d.p.s.k.)*, and experimental equipment for this system was already available[19]. Furthermore 4-phase d.p.s.k. is easy to analyse, and is usually taken as the benchmark against which other modulation systems are compared. In the absence of special requirements, such as the need for a constant modulation envelope to pass through limiting amplifiers, 4-phase d.p.s.k. gives near optimum performance.

Thus, 4-phase d.p.s.k. modulation was chosen for these preliminary experimental transmissions. The need for 4-phase d.p.s.k. to operate in a linear environment (because of the large amplitude variations in its envelope) was not regarded as a serious disadvantage here, since it was expected that the two sound carriers would be combined before power amplification at the transmitter. Thus some amplitude-modulation would inevitably occur in the combined signal regardless of whether or not the second sound signal was constant-envelope.

Details of the implementation of the experimental 4-phase d.p.s.k. system are given in Section 4.1.

*This modulation system is now usually referred to as q.p.s.k. but the terminology 4-phase d.p.s.k. will be used in this report to accord with that used in earlier BBC Reports.

2.3. Choice of frequency and level for the second sound carrier

The relative levels of the vision and sound carriers, and the frequency-spacing between the two sound carriers, have to be chosen to give good compatibility with existing receivers, whereby interference to the picture or main sound channels is kept to a minimum. The frequency and level of the second sound carrier must also be chosen so that the digital system will work reliably throughout the service-area for normal television reception. Inevitably, these two requirements of compatibility and ruggedness tend to conflict, and a compromise has to be sought.

Theory and initial laboratory tests indicated that, with UK System I, and in order to avoid interference to or from the frequency-modulated primary sound signal, the additional digitally modulated sound carrier would need to be spaced at least about 6.5 MHz above the vision carrier (i.e. 0.5 MHz above the rest frequency of the primary sound signal), and at a level of between 20 to 25 dB below it*. This is a larger frequency spacing than that used in the earlier BBC tests on an analogue two-carrier system, where a spacing of about 6.3 MHz was found to be best. This is because of the greater bandwidth of the digitally modulated signal compared with that of the analogue frequency-modulated signal. Here, the overall bandwidth of the transmitted digitally modulated signal is slightly greater than 700 kHz.

The upper limit on the spacing of the second sound carrier from the vision carrier was determined by considerations of adjacent-channel interference, both from the viewpoint of interference from the digitally modulated signal into the vestigial sideband of the upper adjacent channel, and vice-versa (see spectrum diagram shown in Fig. 1).

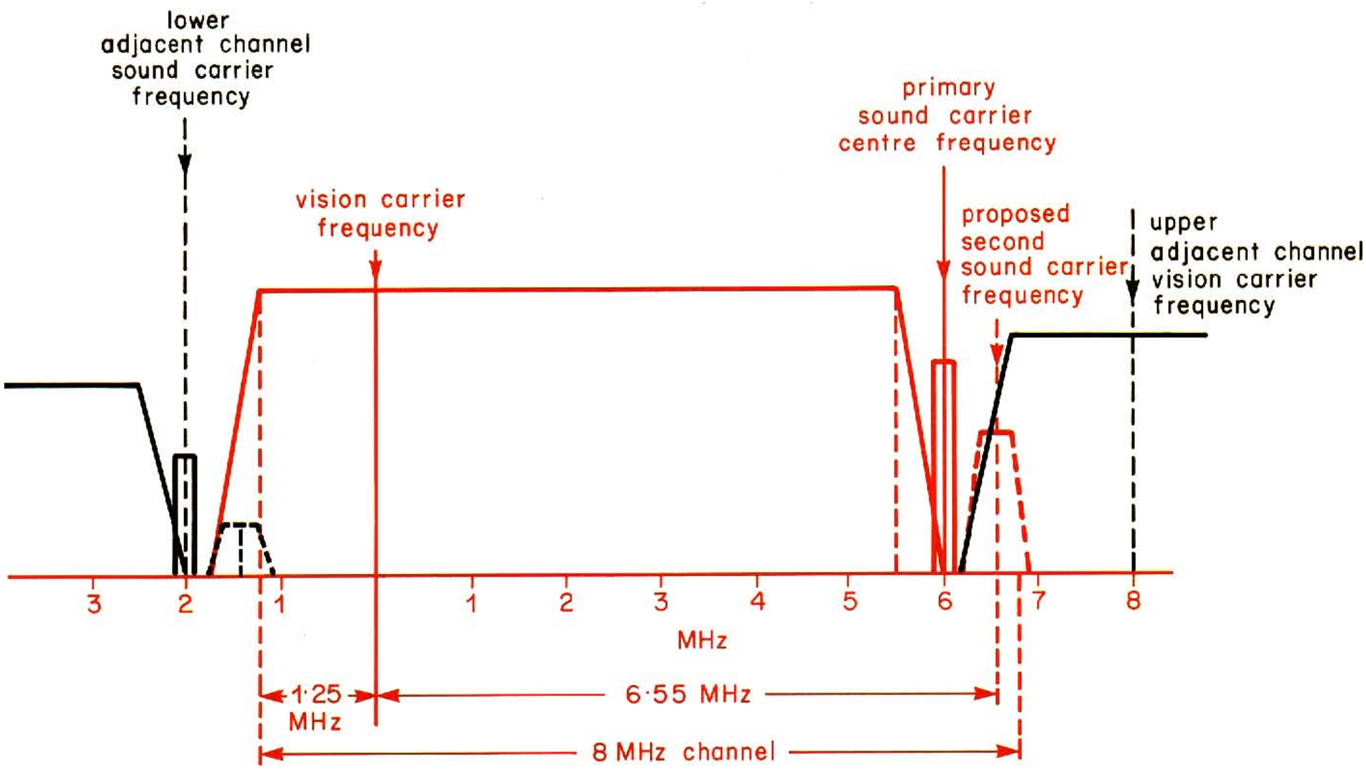


Fig. 1 — The frequency bands occupied by the colour picture components and sound signals from ideal transmitters with the proposed digital sound system added.

Laboratory tests were made of the effects of adjacent-channel interference. These indicated that, with the digitally modulated second sound carrier at a level of 20 dB below the vision carrier level, interference from the digitally modulated second sound carrier into the upper adjacent channel would not be a problem with the existing planning protection ratio of 9 dB applicable for interference in this direction.[20]

The primary sound carrier was always found

* Throughout this report the vision carrier level is taken as the peak vision carrier power at the tips of the sync. pulses, and the levels of the primary and secondary sound carriers refer to the respective levels of the unmodulated carriers.

to be the limiting factor for interference into the upper adjacent channel. This remained true even when the level of the primary sound carrier was reduced by 3 dB to 10 dB below the vision carrier.

On the other hand, interference from the upper adjacent channel into the digital channel seemed more likely to be a problem because the protection ratio is only 3 dB for this direction[20]. The interference falling into the digital channel from the vestigial sidebands of the vision signal in the upper adjacent channel is, of course, picture dependent, and detailed studies of the power-density spectrum of this interference were made with a variety of picture signals. It was found that, as would be expected from the vestigial sideband shaping, the power-density spectrum of the interference falling into the digital channel was triangulated, the power-density decreasing with increasing frequency spacing from the interfering vision carrier. Thus, adjacent-channel interference considerations indicated that the frequency of the digitally modulated second sound carrier should be kept as close as possible to that of the wanted vision carrier. On the other hand, considerations of avoidance of interference from the f.m. primary sound carrier required that this spacing should be at least 6.5 MHz.

A frequency-spacing of 6.55 MHz above the wanted vision carrier was therefore selected as the best compromise. The laboratory work indicated that, with this frequency-spacing and with the level of the second sound carrier 20 dB below the peak vision carrier level, the protection ratios existing would adequately safeguard the performance of the digital system.

Because of the relatively broad and noise-like spectrum of the digitally modulated second sound carrier, the detailed frequency-spacing between the vision carrier and the additional sound carrier is not critical. This is in contrast to the analogue two-carrier system, where a precision frequency-offset, related to television line and field frequencies, is found to be beneficial to minimise the visibility of interference patterns.

2.4. Reduction in the level of the primary sound carrier

As noted in Section 1, earlier over-air tests of the analogue two-carrier sound system had shown that, when introducing a second sound carrier, it was necessary to reduce the level of the primary sound carrier in order to reduce the level, and thus the visibility of the patterning caused by intermodulation products (i.p.s) due to non-linearities in transmitters and transposers*. This reduction in level of the primary sound carrier was found to increase the buzz-on-sound problem with many existing receivers.

With the digital system it was expected that, because of the relatively low level of the second sound carrier and the decreased visibility of any i.p.s due to the broader and more noise-like spectrum of the digitally modulated carrier, the reduction, if any, in the level of the primary sound carrier could be kept small. However, preliminary tests with a sound transmitter at Crystal Palace and laboratory tests with a 200 W transposer, indicated that a reduction of about 3 dB would be necessary in the level of the primary sound carrier to about −10 dB with respect to the peak vision carrier level. This result was also confirmed during preliminary experiments at the Wenvoe transmitter.

3. Organisation of the field-tests

3.1. General

Although it was recognised that formal tests of the compatibility of the proposed digital system would ultimately be needed, laboratory tests and earlier over-air tests of the analogue two-carrier system had given considerable confidence in the compatibility of the proposed system. On the other hand, the ruggedness of the proposed system still needed to be evaluated, and the field-tests described here were therefore designed primarily to test this especially with regard to:

1) The effects of multipath propagation.

2) The effects of the characteristics of the transmitter (s).

3) The effects of chains of transposers.

Although the specification of the transmitter and transposers is within the control of the broadcaster, economic and practical considerations make it desirable that any proposed new service should not require major re-engineering of these items.

In order to test the effects of a long tandem chain of transposers, it was decided to perform the field-tests from the BBC-2 transmitter at Wenvoe in South Wales, where a large number of transposers

* A transposer is a transmitter, usually of low power, fed by an off-air receiving system in which the r.f. signal is not demodulated but is changed only in frequency before retransmission.

are used to serve the Valleys.

Because the compatibility of the proposed system was not proven, it was essential to conduct the over-air tests during the night and early morning outside normal programme hours. This gave the advantage that the picture and sound signals could be specially chosen to suit the tests, but gave the disadvantage that the tests had to be done whilst other transmitters were off-air. Thus it was not possible to check that the orientation of the receiving aerial at each test site gave best reception of all four channels, as would be the case in practice. Rather, the aerial was steered at each test site for best picture and primary sound for the BBC-2 channel being used for the tests.

Two weeks, 10th – 15th and 24th – 28th October, were available for the field-tests, during which time the proposed digital system was radiated for seven nights for an average period of about seven hours per night.

3.2. Wenvoe transmitter and its transposer chains

A map showing the location of the Wenvoe transmitter and its approximate service area, is given in Fig. 2. This map also shows the locations of the transposers investigated during these field-tests. The chain of transposers which was principally investigated is that which runs from Ebbw Vale, via the Abergavenny, Brecon, and

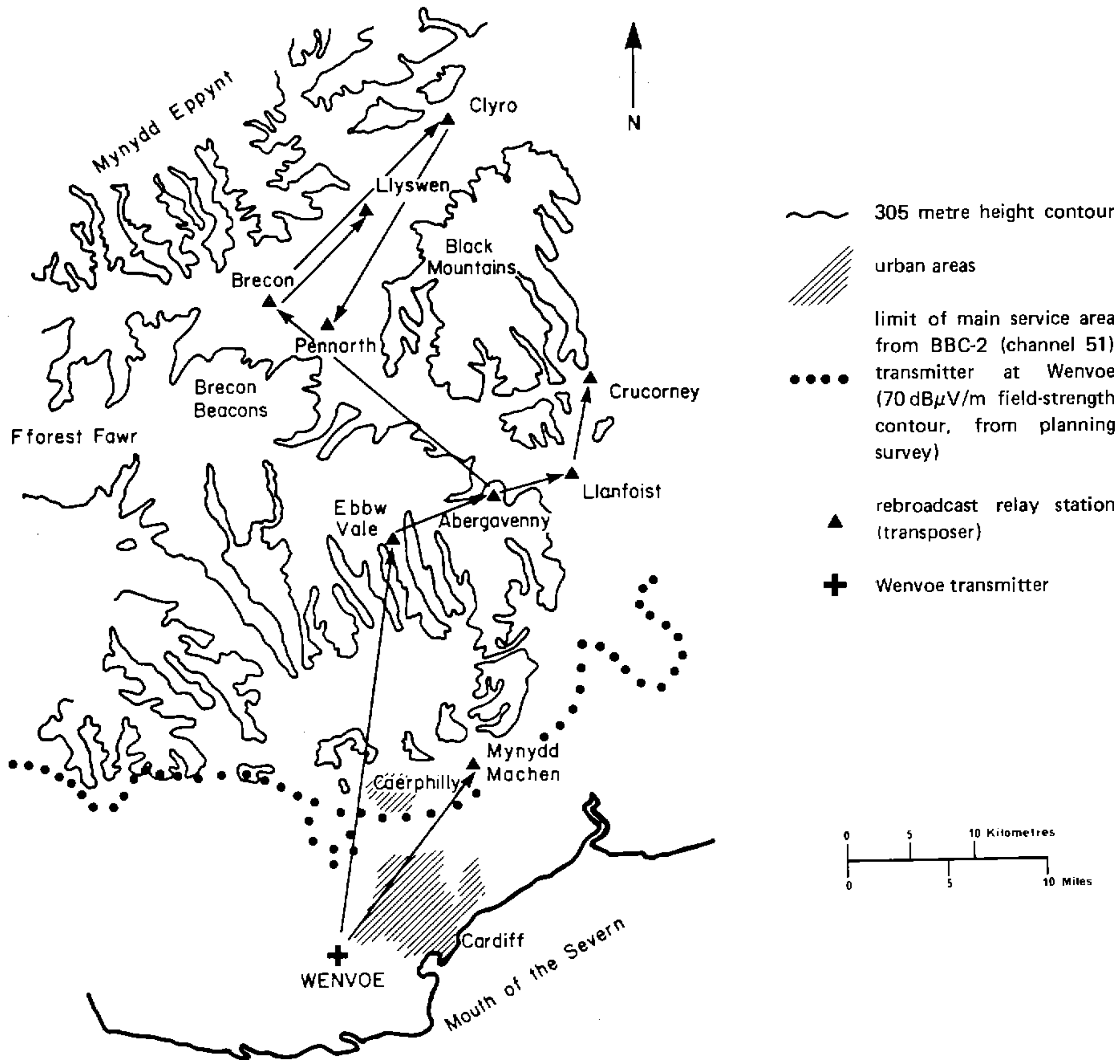


Fig. 2 – Service area of the Wenvoe transmitter and its transposers.

Clyro transposers, to that at Pennorth. It is believed to be the only such chain of five transposers in tandem in the UK, and poses a severe test for any proposed system.

The chain as far as Brecon was commissioned in 1973, and therefore comprises mainly older transposer equipments. To include examples of the latest generation of transposer equipments, measurements were also made when receiving signals from the more recently commissioned transposers at Llyswen, Llanfoist, and Crucorney. The principal characteristics of all of these transposers are summarised in Appendix 1.

3.3. Measuring the quality of the received signal

In addition to making detailed measurements of the quality of the received 4-phase d.p.s.k. signal at various test-sites, it was also desired to correlate the reception quality of the 4-phase d.p.s.k. signal with that of the normal picture, sound, and teletext signals, and to assess the performance of the transposer chains as measured with conventional test-signals. The picture content, the sound signal modulation and the test-signals carried in the field-blanking period were therefore carefully chosen so as to yield the maximum information in the time available. Details of all of these signals are given in Section 4.2.2.

A set of standardised measurement techniques was devised and most waveform measurements were made by photographing the relevant section of the waveform together with calibration markers, so that a more detailed study of the waveforms could be made later. Details of the measurement procedures used are given in Section 4.4.

The receiving, decoding and measuring equipment was installed in a specially adapted measurement vehicle. Details of this vehicle and its equipment are given in Section 4.3.

3.4. Selection of test-sites

Because of the necessarily restricted number of different sites which could be visited during the field-tests, no attempt was made to obtain a complete survey of the service areas of the Wenvoe transmitter and its transposers. Rather, the test-sites were chosen in order to assess the effects upon reception of the experimental digital system, of a wide variety of different propagation conditions, and to isolate the effects caused by the transmitter and transposers. The sites were selected:

1) From earlier reception surveys and local knowledge.

2) To give a variety of reception conditions.

3) To include at least one clean site (i.e. virtually free from multipath effects or other interference) in the service area of each transposer.

In some cases, excursions were made outside the normal service area and to sites with little or no population, in order to gain a wide range of reception conditions.

A map showing the location of the sites tested is given later in the report (see Fig. 11).

4. The experimental system and test procedure

4.1. The experimental 4-phase d.p.s.k. equipment

4.1.1. 4-phase d.p.s.k. modulator and demodulator

Block diagrams of the experimental 4-phase d.p.s.k. modulator and demodulator equipments are shown in Figs. 3(a) and 3(b) respectively (shown opposite). The standard i.f. of 10.7 MHz was chosen for convenience of instrumentation. The spectrum-shaping of the digitally modulated signals was determined by filters F_1 and F_2, shown in Figs. 3(a) and 3(b) respectively. These filters were designed such that the effective overall spectrum shaping, from the baseband input of the modulator to the baseband output of the demodulator, was 100% cosine roll-off[13,19]. The distribution of filtering between the modulator and demodulator was chosen to optimise the noise performance of the system when operating under peak (rather than mean) power limited conditions. This required most of the filtering to be at F_2, i.e. in the demodulator, so that F_1 was simply a relatively broad-band rectangular filter which only served to remove components beyond the main lobes of the spectrum of the transmitted signal.

Further details of the implementation of the 4-phase d.p.s.k. modulator and demodulator are given in References[16,17,19,21].

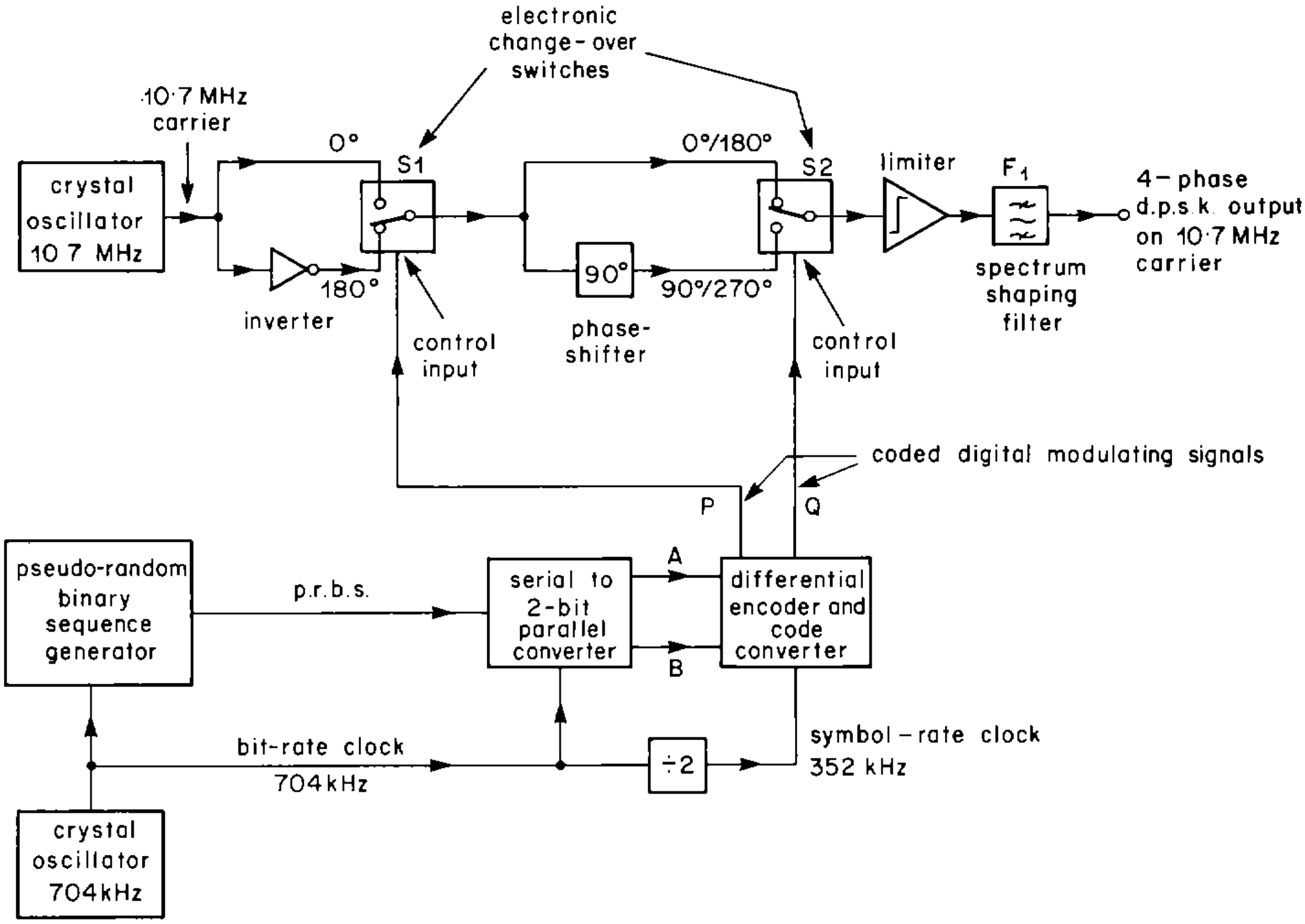


Fig. 3(a) — DPSK modulator and test-pattern generator.

4.1.2. UHF up-converter and u.h.f. receiver

A block diagram of the frequency-converter used to translate the 10.7 MHz i.f. output of the modulator to u.h.f. is given in Fig. 4(a), and that of the u.h.f. receiver is given in Fig. 4(b). The filtering in these units was all relatively broad-band, and was designed to make no contribution to the data-signal spectrum shaping.

The u.h.f. receiver was based upon a BBC-designed rebroadcast link (RBL) receiver which was originally fixed-tuned. In order to be able to change receiving channels during these field-tests, the normal crystal-controlled local-oscillator in the receiver was replaced with a programmable frequency synthesiser, and the u.h.f. front-end filter replaced by a bank of u.h.f. channel filters which were tuned to the appropriate frequencies for BBC-2 Wenvoe and its transposers. The appropriate channel filter for reception from any given transmitter or transposer was selected by plugging.

As indicated in the block diagram of Fig. 3(b), two stages of frequency conversion from u.h.f. to the demodulator i.f. input frequency of 10.7 MHz were used in the experimental receiver. This was done mainly to enable the original RBL receiver i.f. unit, whose nominal frequency is 39.5 MHz (vision carrier) to be retained. The amplitude/frequency and group delay characteristics of this i.f. unit were good and caused little degradation to the received 4-phase d.p.s.k. signal. Similar, or perhaps even better, results would be expected from a modern domestic receiver i.f. strip using surface acoustic wave (SAW) filters.

4.1.3. Laboratory performance of the experimental digital system

The eye-pattern of one of the demodulated data streams, with a pseudo-random binary sequence (p.r.b.s.) of length $2^{15} - 1$ bits as a modulating signal, and the u.h.f. up-converter output connected via a suitable attenuator into the u.h.f. receiver input, is shown in Fig. 5. The measured eye-height* is approximately 85%.

*In this report we define eye-height as $2x/x + y$, where x is the minimum distance from the slicing level to the demodulated signal level at the sampling instant and y is the maximum distance.

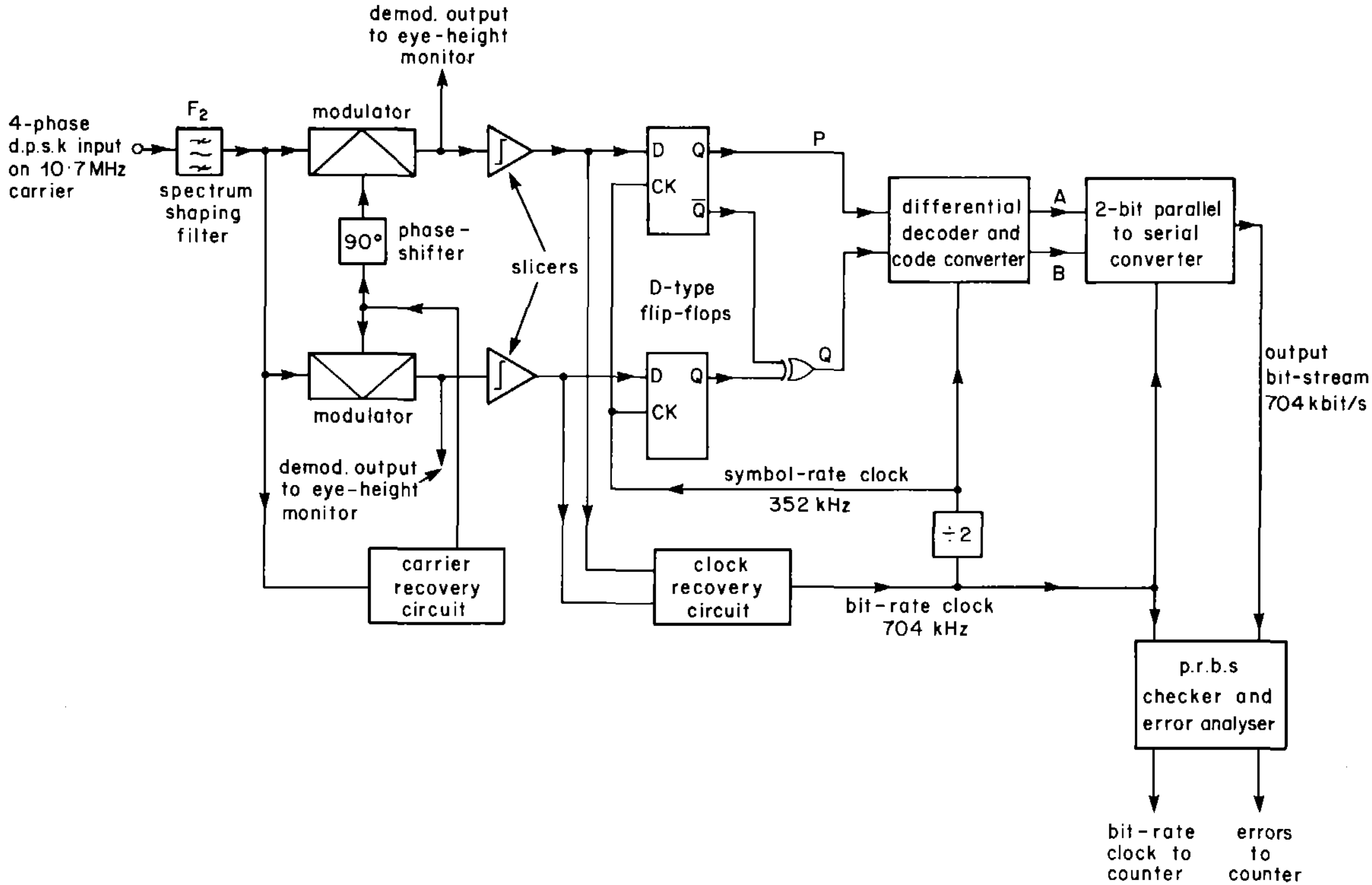


Fig. 3(b) – DPSK demodulator and test-pattern checker.

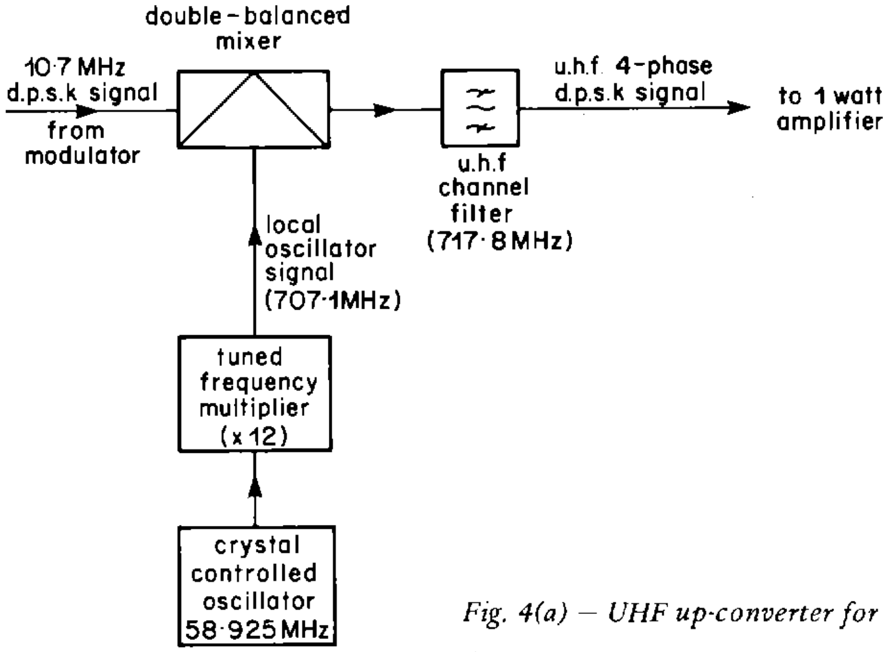


Fig. 4(a) – UHF up-converter for 4-phase d.p.s.k. source equipment.

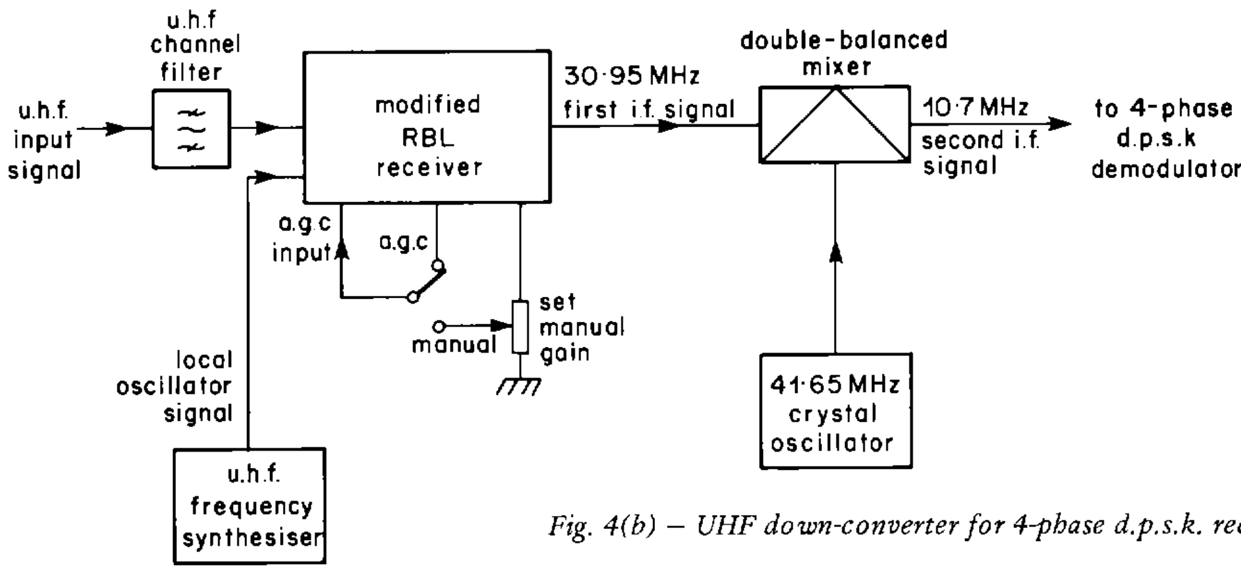


Fig. 4(b) – UHF down-converter for 4-phase d.p.s.k. receiver.

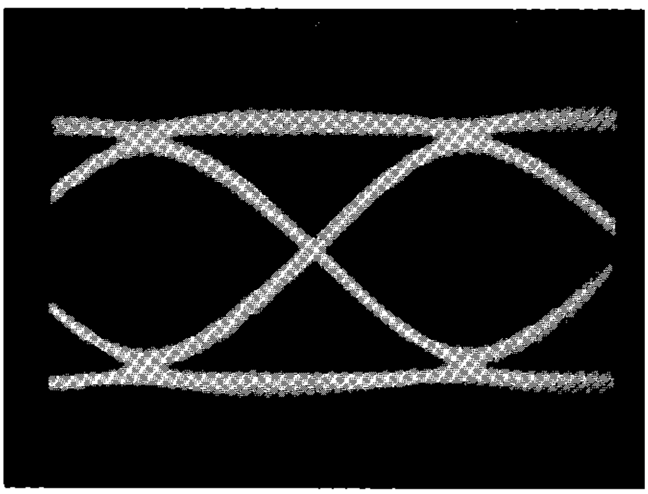


Fig. 5 – Eye diagram of the received 4-phase d.p.s.k. signal under laboratory conditions.

The bit error-rate versus carrier-to-noise ratio curve for this equipment is shown in Fig. 6. These measurements were made by adding band-limited Gaussian white noise at the input to the u.h.f. receiver via a variable attenuator. Care was taken to avoid overloading any of the u.h.f. amplifiers with the noise signal. The carrier power and noise power were measured using a true r.m.s. power-meter and a filter of known noise bandwidth. The results were then normalised to give the carrier-to-noise power in a bandwidth numerically equal to the symbol rate of the system, i.e. 352 kHz. As may be seen from Fig. 6, the experimental equipment performs to within about one decibel of the result expected from theory when assuming ideal implementation.

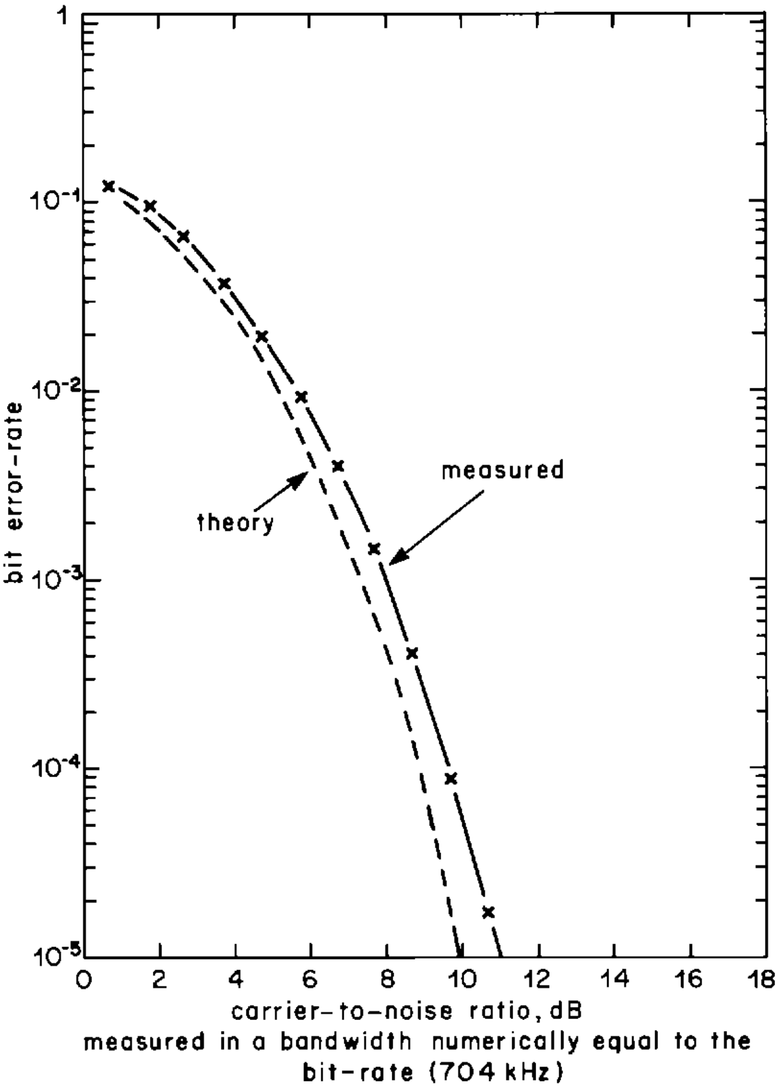


Fig. 6 — Bit error-rate versus carrier-to-noise ratio for the experimental 4-phase d.p.s.k. equipment.

4.2. Arrangements at the transmitter

4.2.1. Addition of the digitally modulated second sound carrier

The block diagram of Fig. 7 shows the way in which the BBC-2 transmitter at Wenvoe was modified to permit the digitally modulated second sound carrier to be added. The BBC-2 u.h.f. transmitter at Wenvoe is built in two halves, A and B, with their signals combined at the output. Thus the u.h.f. output signal of the 4-phase d.p.s.k. modulator and up-converter, was split into two via a 3 dB coupler, and the two signals added via further 3 dB couplers into the drives to the A and B sound klystrons at about the 1 watt level. Manual phasing between the A and B feeds of the 4-phase d.p.s.k. signal was provided using a variable length u.h.f. transmission line (trombone line) which also served to remove the 90° phase-shift introduced between the A and B feeds by the 3 dB coupler.

The primary and secondary sound signals were then amplified together in the two sound transmitters. The sound transmitter output klystrons were retuned, and their bandwidth increased to accommodate the additional signal by loading their 2nd and 3rd cavities.

The output klystrons are normally run hard into saturation in the interests of efficiency. This mode of operation would have produced intolerable intermodulation products (i.p.s.) between the two carriers, and so it was necessary during the period of the tests to increase the standing currents so as to operate in a more linear (but less efficient) mode. (This increase in standing current also served to make good some of the gain lost by broad-banding.) Even so, in order to reduce the i.p.s. between the two sound signals to an acceptable level, it was found necessary to reduce the drive level of the primary sound signal by about 3 dB, as had been expected from the preliminary tests described in Section 2.4. Thus,

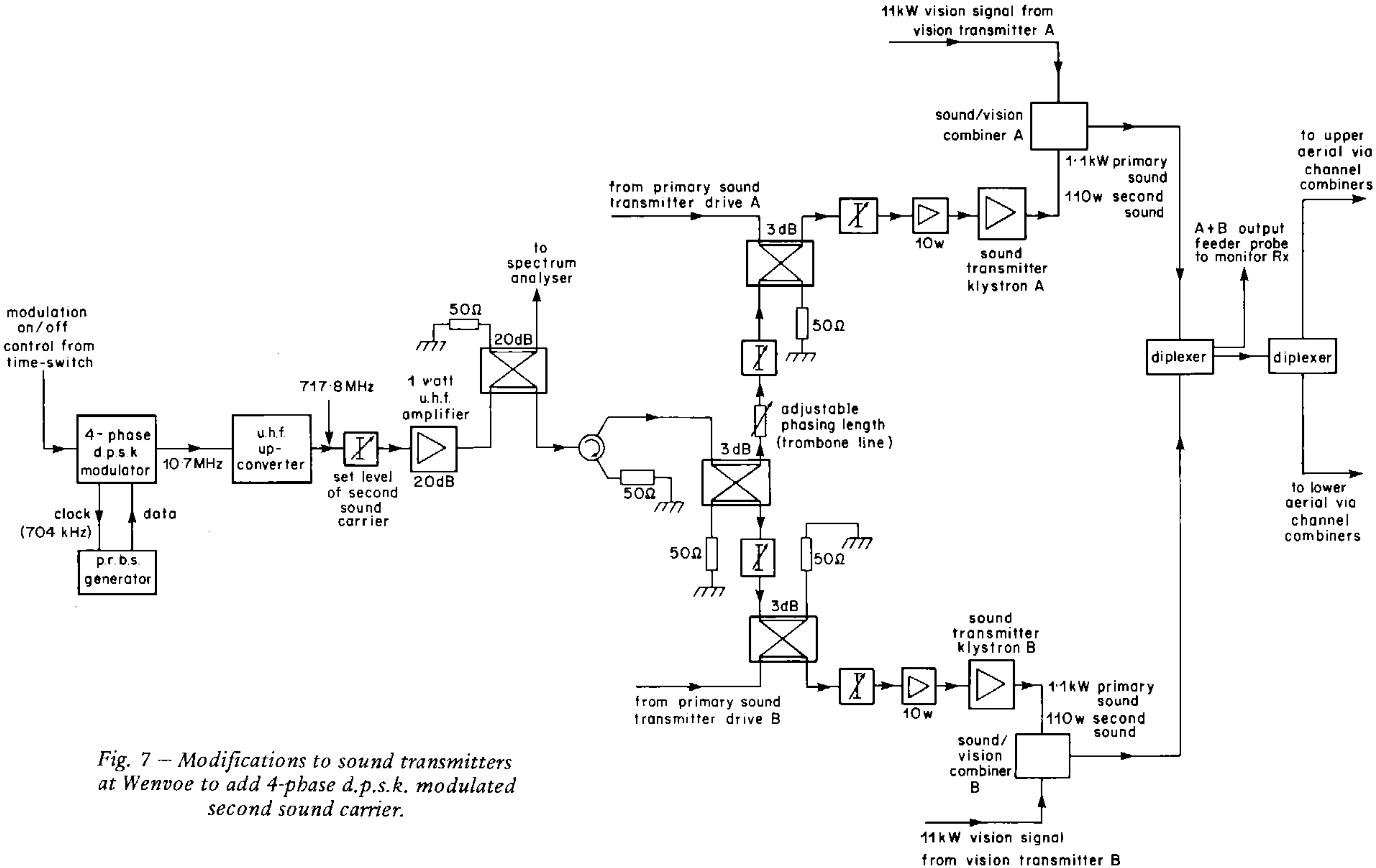


Fig. 7 – Modifications to sound transmitters at Wenvoe to add 4-phase d.p.s.k. modulated second sound carrier.

during the tests, the level of the primary sound carrier was $-10\,dB$ relative to the peak vision carrier level. With these modifications, some residual i.p.s between the two sound signals were still measured, but by careful adjustment of the phasing trombone line, near cancellation of the i.p.s generated in the two halves of the transmitter was obtained. Thus the levels of the i.p.s at the combined output were reduced to levels too low to affect compatibility.

4.2.2. Picture, sound and test signal origination equipment

A block diagram showing the overall arrangement of the picture, sound and test signal origination equipment is shown in Fig. 8 (shown overleaf).

The video signals available were:

1) Electronically generated 'test-card G'.
or
2) 95% colour bars 'dipped-in-grey'.

The test card G signal was particularly useful when assessing picture degradation due to multipath propagation ('ghosts') at the various receiving sites, whilst the colour bars 'dipped-in-grey' signal (in which the chrominance signal is switched off in the lower third of the picture to produce a stepped grey-scale) was particularly useful when assessing the visibility of i.p.s generated by the transmitter and transposers.

The test signals inserted into the field-blanking interval are listed below:

Lines 15, 16, 17, 18, 328, 329, 330, 331	–	teletext data signals, nominal data level 0.46 volts
Lines 19, 332	–	insertion test-signal, including 2T luminance pulse and bar, 10T composite pulse, and chrominance staircase.
Lines 20, 333	–	multiphase waveform comprising ten 10T composite pulses of test-tones. The frequency of the test-tone signal within the 10T envelope ranges from 0.5 MHz to 5 MHz in 0.5 MHz steps.
Line 334	–	2T luminance pulse (used for objective measurements of echoes).

The modulating signal for the primary sound channel was music derived from a high-quality cassette tape player. A short repeated excerpt of loud Latin American music was chosen so as to ensure that the primary f.m. sound carrier excursed its full deviation range.

The data signal conveyed by the 4-phase d.p.s.k. system during the tests was a p.r.b.s. of length $2^{15} - 1$ bits. This signal was chosen in preference to digitally coded sound signals to facilitate objective measurements of errors at the decoder.

To facilitate objective measurements of i.p.s produced by the transmitter and transposers, a simple mechanical time-switch was provided, whereby the composite video and sound signals could, at regular intervals, be replaced by a 4-tone test comprising:

Vision carrier – relative level (sync. tips)	0 dB
Colour subcarrier – relative level	−17 dB
Primary sound carrier (unmodulated)	−10 dB
Second sound carrier (unmodulated)	−20 dB

Unfortunately, because the automatic gain control circuits of the transposers rely upon the presence of line-syncs, line-syncs had to be included in the vision modulating signal for the 4-tone test. Spectral components from these line-syncs make the spectrum analyser photographs difficult to interpret and mask certain low-level i.p.s.

4.3. The measuring vehicle

4.3.1. General

The receiving and data decoding equipment was installed in a BBC Engineering Information Department Survey Vehicle. A block diagram of the equipment in the vehicle is shown in Fig. 9.

The vehicle was equipped with two 300 VA square-wave inverters which provided 240 V a.c. electrical power for most of the equipment. The u.h.f. receivers and 4-phase d.p.s.k. demodulator were run off a separate 100 VA sine wave inverter, in order to minimise the risk of interference from the inverters into the d.p.s.k. equipment. All of the inverters were fed from the vehicle's 12 volt electrical system.

Two-way communication with Wenvoe transmitter was provided by a v.h.f. radio intercomm.

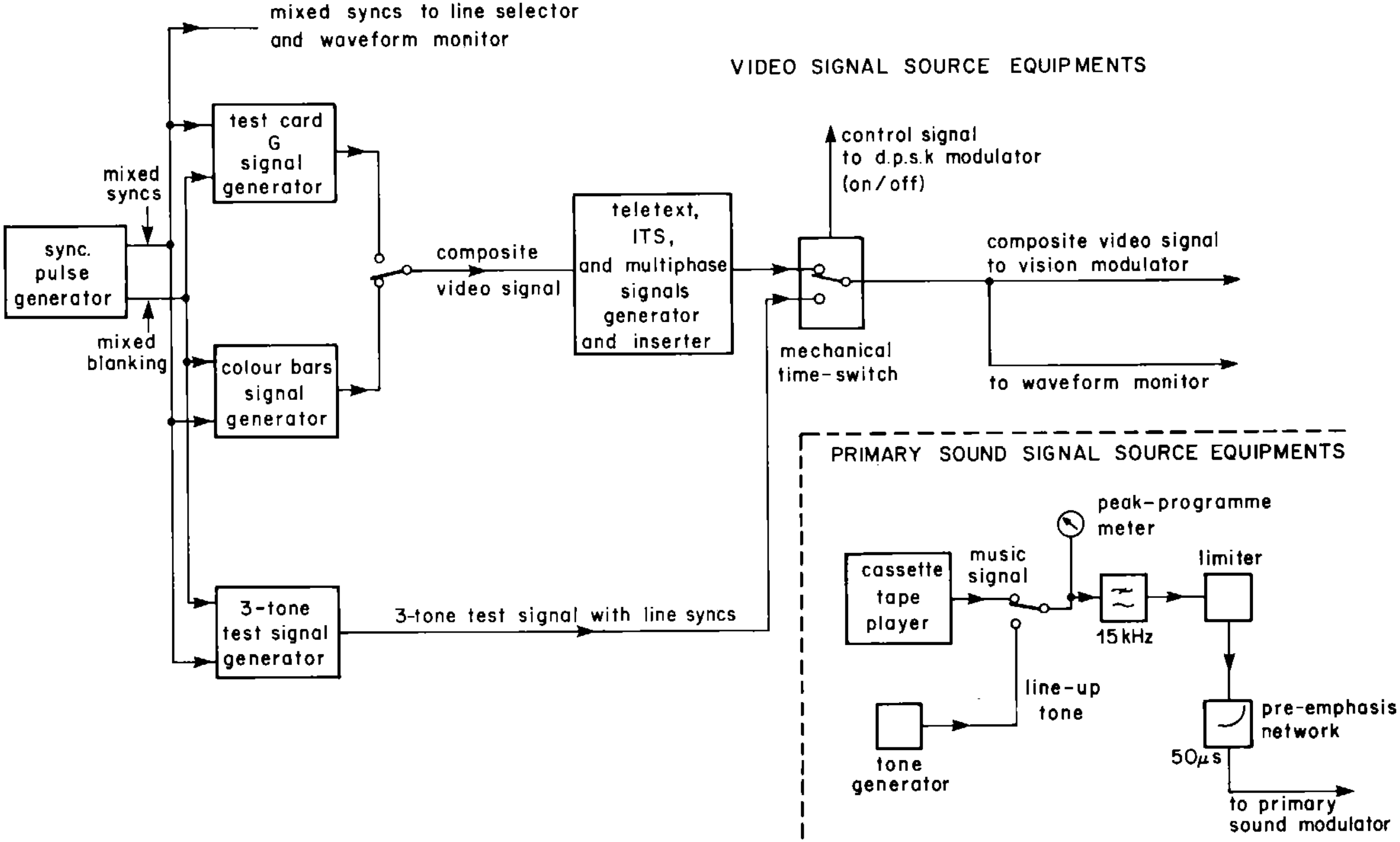


Fig. 8 – Video and primary sound signal source equipments.

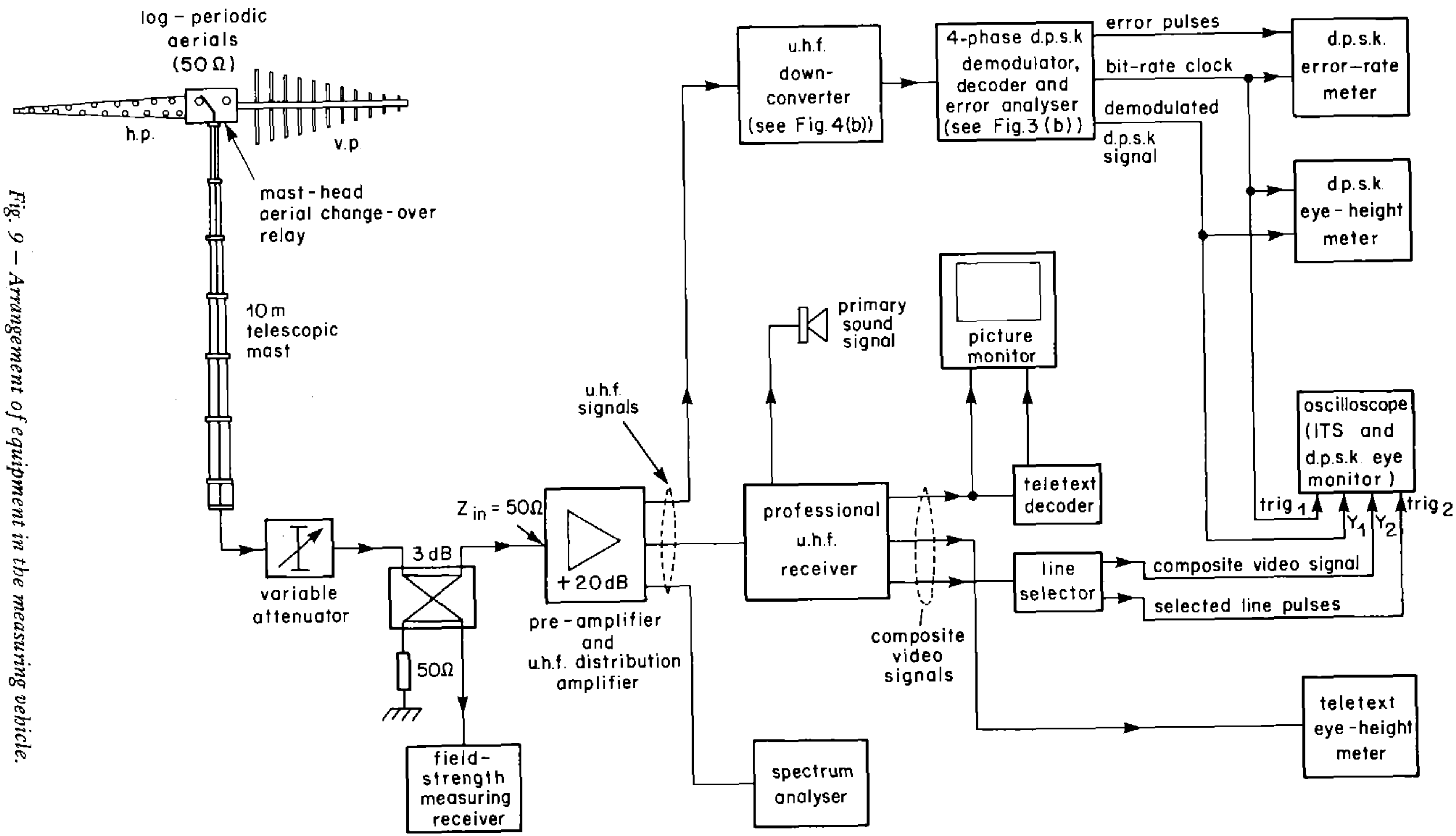


Fig. 9 — Arrangement of equipment in the measuring vehicle.

4.3.2. Aerials and u.h.f. distribution system

The measuring vehicle was fitted with two u.h.f. log-periodic aerials mounted upon a steerable 10 metre telescopic pneumatic mast. One aerial was orientated for horizontally polarised transmissions and the other for vertically polarised transmissions. Selection of the appropriate aerial was performed remotely from inside the vehicle, using a co-axial relay mounted at the mast-head.

The u.h.f. aerial signal was first fed to a calibrated variable attenuator which was used when required to simulate a lower field-strength receiving condition. The signal at the output of the attenuator was split into two paths by a 3 dB coupler. One path fed the u.h.f. field-strength receiver directly, the other fed a pre-amplifier which provided amplified (+20 dB) u.h.f. signals to the other receivers. The noise figure of this pre-amplifier was about 9 dB. This arrangement ensured that, except in the case of the field-strength measuring receiver, the major noise contribution was from the pre-amplifier rather than from separate receiver front-ends and thus would not vary from receiver to receiver. On the other hand, the field-strength receiver was fed directly from the aerial so that its calibration would not depend upon the stability of the gain of the pre-amplifier.

4.3.3. UHF receivers

Three u.h.f. receivers were used:

1) A u.h.f. programmable digital field-strength measuring receiver of BBC design[22].

2) A professional u.h.f. receiver, which was used to drive the picture monitor and teletext eye-height meter.

3) The modified RBL receiver used to drive the 4-phase d.p.s.k. demodulator, as described in Section 4.1.2.

4.3.4. Teletext eye-height meter

A BBC designed teletext eye-height meter[23], was included in the measuring equipment so that the effects of multipath propagation upon the eye-height of the 4-phase d.p.s.k. system could be correlated with the effect upon the teletext eye-height.

4.3.5. 4-phase d.p.s.k. eye-height meter

Simple, manually operated, equipment was provided to facilitate accurate measurements of the eye-height of the demodulated 4-phase d.p.s.k. signals. This equipment comprised a voltage comparator, whose threshold was variable under the control of a calibrated multi-turn potentiometer, and a sampling circuit driven by an appropriately phased version of the recovered bit-rate clock. Using this equipment the maximum and minimum voltage levels of the demodulated 4-phase d.p.s.k. signal at the sampling instants could be determined and thus a measure of the eye-height of the received signal calculated.

4.3.6. Error analysis equipment

The data from the output of the 4-phase d.p.s.k. demodulator was fed to a purpose-built error analysis unit. As a first step, the received p.r.b.s. was checked for errors using a self-synchronising decoder of novel design. A direct measurement of the bit error-rate in the received data was obtained by using the bit error-rate output of the p.r.b.s. checker to drive a frequency meter, whose external reference input signal was the bit-rate clock.

Additional logic circuitry within the error analysis unit permitted measurements to be made of the frequency of occurrence of multiple errors. This information is of help in designing the error protection for a final system.

4.4. Procedure used at test-sites

A standardised pro-forma was produced to record the results at each test-site. An example of a completed pro-forma for a particular site in the service area of the Pennorth transposer (the last in the chain of five tandem transposers) is given in Fig. 10.

On arriving at a test-site, the telescopic mast was raised and the appropriate aerial polarisation selected. The mast was then steered whilst observing the quality of the received picture and listening to the primary sound signal until the best result was obtained.

The mast was then locked into place before starting to make measurements. As was noted in Section 3.1., this procedure was necessarily somewhat unrealistic because during the times when the tests were being performed the transmitters of the other three services normally available were not on-air. Thus the aerial could not be orientated

Digital Two-Carrier Sound with Television Tests in Wales

Site No. 14 Town Trefecca Map Ref. SO 143322 Date 26-10-83

Transmitter Pennorth V.P./~~H.P.~~ Site Description Outside College Time 05-33.

Channel No. 26

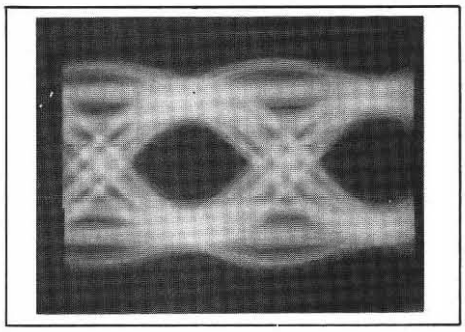
Log-Periodic Aerial at 10m ; Vision F/S 78·0 dB μV/m ; Sound F/S 67·0 dB μV/m

Feeder Atten. to BER $\approx 10^{-2}$ = 20·0 dB Eye height (x) min 0·34 V

a.g.c meter +1·0 with 0 dB in feeder (meters) (y) max 1·79 V

Bit error rate = 0 errors in 10,000 bits $\frac{2x}{y+x} \times 100\%$ = 32%

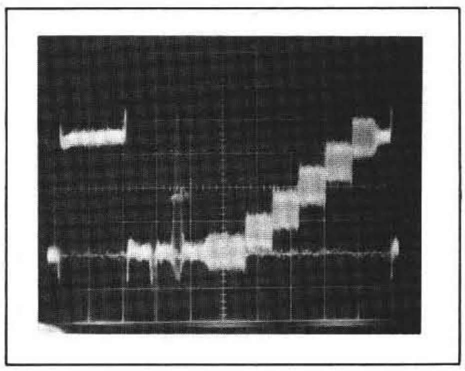
Multiple Error Analysis	
No. of errors in 100-bit blocks m	Percentage 100-bit blocks with m or more errors
0	100
1	
2	
3	
4	
5	



0·5 v/div, 0·57 μs / div : d.p.s.k eye

Assessment of Picture (Test Card G) — 1 2 3 4 5: 4 marked (*)

Impairment to Picture: Slight random noise



0·2 v/div, 7 μs / div test-line (19)

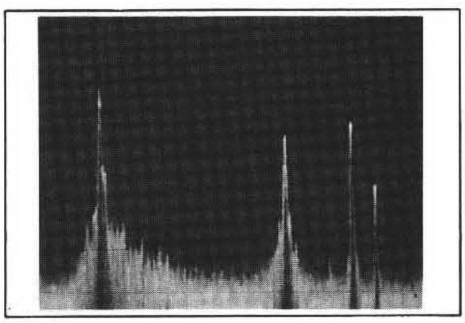
Assessment of Primary Sound ('Chiariana') — 1 2 3 4 5: 5 marked (*)

Impairment to Primary Sound: None

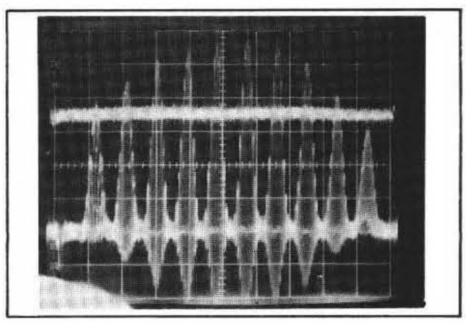
Ceefax Error-rate 0

Ceefax Eye-height 60 %

Ceefax Slice-level 50 % (adaptive)



10 dB / div, 1MHz/div, optimum B/W = 30 kHz



0·2 v / div, 7 μs / div multiphase line (22)

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Fig. 10 – An example of a completed measurements pro-forma.

for best compromise of reception on all four services, as would normally be done by an aerial-rigger. In practice, however, this shortcoming is only likely to affect the results obtained at the few sites where very severe multipath propagation was found. The quality of the received picture and primary sound were subjectively assessed using the CCIR 5-point Quality Scale (see Table 2). Because of the difficult viewing and listening conditions in the measuring vehicle, and the very limited number of observers (two), these subjective assessments can only be taken as approximate.

The field strength margin available for 4-phase d.p.s.k. reception at each test-site was measured using the following method: first the field-strengths of the vision and primary sound carriers were measured with the attenuator in series with the aerial feed set to zero; then this attenuator was adjusted until the measured bit error-rate was 5×10^{-3}; the effective field-strength thus simulated was then calculated by subtracting the attenuator setting (in dBs) from the previously measured field-strength. At all sites, brief subjective assessments were made of the qualities of both the received picture and the primary sound signals at the normal field-strengths (i.e. with the attenuator set to zero), and the results were recorded in the boxes provided on the pro-forma. At some sites, supplementary subjective assessments were also made at the simulated low field-strengths. All other measurements were made with the attenuator set to zero, except in areas of very high field-strength, where some attenuation was introduced to avoid overloading the receiving u.h.f. pre-amplifier.

TABLE 2

CCIR Picture Grades	
Grade	Quality
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

5. Analysis of results

5.1. Overall view

44 sets of measurements were made at 30 different receiving sites. Some sites were visited more than once in order to check for consistency over the 3-week period of the tests, and at some sites reception was possible from more than one station; separate sets of measurements were made in these cases.

The locations of the test-sites are shown on the map, Fig. 11. Also shown on this map are the nominal service area limit contours (70 dBμV/m for a station transmitting in Band V and 64 dBμV/m for a station transmitting in Band IV)[24] for each station*.

The test-sites have been numbered 1 to 30 on the map to enable individual sites to be referred to in this analysis of the results. The test-sites have also been colour coded on the map as follows:

Green = reference ('clean') sites (i.e. the sites used to assess the parameters of the transmitted signals from Wenvoe or a transposer)

Red = site where significant multipath propagation (echoes) was evident.

Blue = all other sites.

At some test-sites more than one colour may be shown; this indicates that signals from more than one station were measured at that site, and that different reception conditions were found in each case.

The results of the 44 sets of measurements are divided into two batches:

1) Results obtained when receiving signals from Wenvoe directly (18 sets of measurements at 15 test-sites).

2) Results obtained when receiving signals via one or more transposer (26 sets of measurements at 15 test-sites).

The results were, in general, found to be consistent and repeatable over the three-week test period.

5.2. Performance of the transmitters and transposers

The performance of the BBC-2 Wenvoe transmitter and some of its transposers, as measured off-air at the respective reference sites during the field-tests, are summarised in Table 3.

*No service area limit contour was available for the recently commissioned transposer at Llyswen.

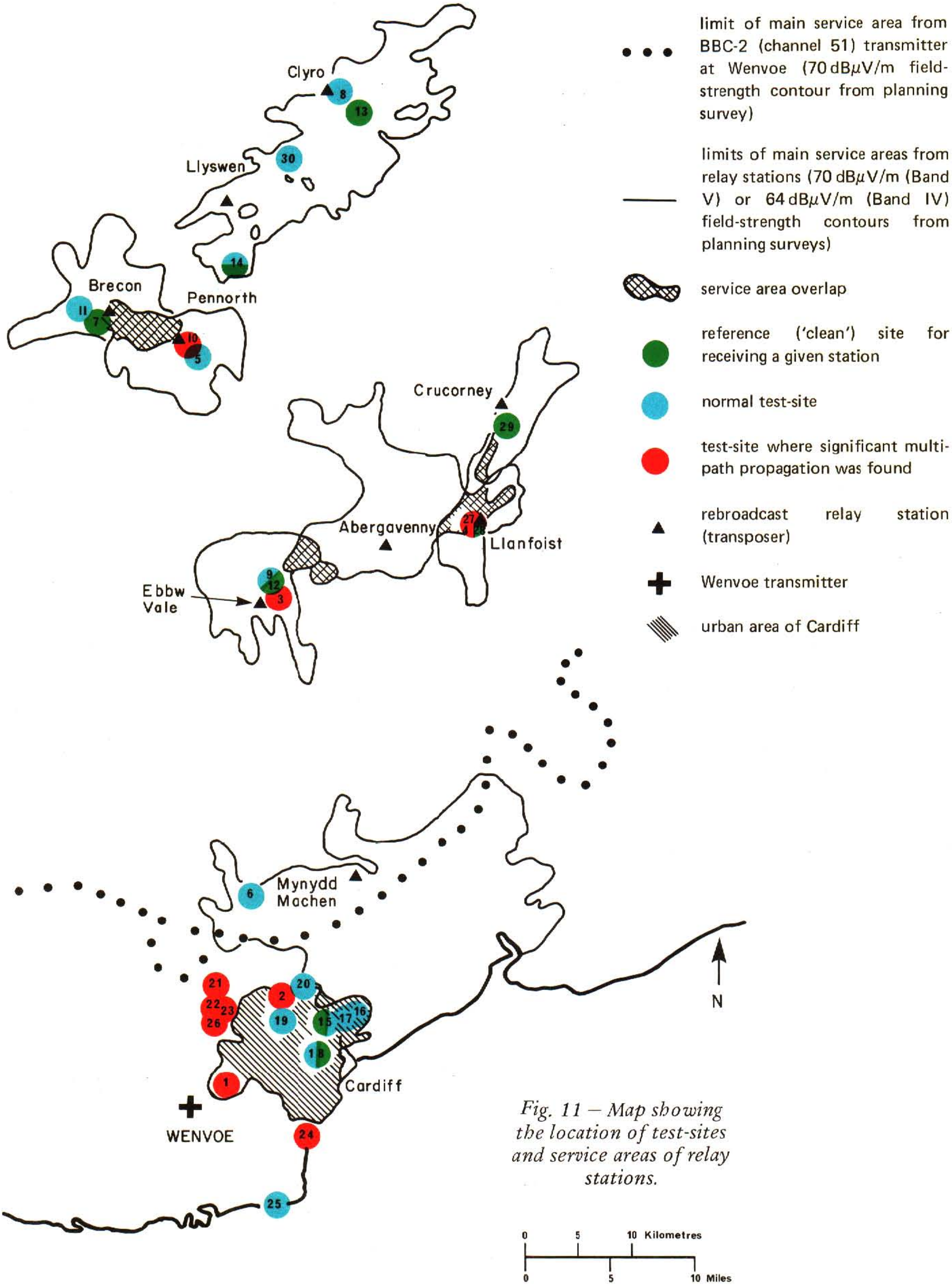


Fig. 11 — Map showing the location of test-sites and service areas of relay stations.

TABLE 3

Measured performance of the Wenvoe transmitter and its transposers

Station	Source	Relative level of the Primary Sound Carrier with respect to the peak vision carrier level	Relative level of the Second Sound Carrier with respect to the peak vision carrier level	DPSK eye-height	Relative level of the 5.45 MHz i.p. with respect to the peak vision carrier level
Wenvoe	–	–10.3 dB	–20.3 dB	52%	–47 dB
Ebbw Vale	Wenvoe	–11.5 dB	–23.5 dB	45%	–46 dB
Abergavenny	Ebbw Vale	–10.0 dB	–21.0 dB	37%	–45 dB
Brecon	Abergavenny	–13.5 dB	–25.0 dB	48%	–45 dB
Clyro	Brecon	–9.8 dB	–21.8 dB	51%	–45 dB
Pennorth	Clyro	–11.0 dB	–25.0 dB	32%	–45 dB
Mynydd Machen	Wenvoe	–11.0 dB	–20.0 dB	59%	–46 dB
Llanfoist	Abergavenny	–11.4 dB	–23.4 dB	39%	–45 dB
Crucorney	Llanfoist	–15.0 dB	–27.0 dB	40%	–45 dB
Llyswen	Brecon	–10.0 dB	–23.0 dB	52%	–45 dB

5.2.1. Performance of Wenvoe transmitter

The eye-height of the demodulated d.p.s.k. signal measured at the reference site was 52%. This is somewhat disappointing when compared with the laboratory result of 85%. It is thought that this degradation of transmitted eye-height was due to group delay variation across the bandwidth of the d.p.s.k. channel in the sound transmitter klystron. Unfortunately, no group delay measuring equipment was available at Wenvoe at the time of the field-tests to enable this hypothesis to be checked.

When receiving signals from Wenvoe transmitter there was no evidence of cross-modulation between the two sound carriers, or, of course, cross-modulation from the vision signal into either sound signal.

The principal extra intermodulation product (i.p.), introduced into the signals from Wenvoe by the addition of the second sound carrier, was at a frequency of 5.45 MHz (i.e. $2f_{SC1} - f_{SC2}$). The level of this i.p. varied somewhat during the 3 week period of the tests but was never measured to be larger than −47 dB with respect to the peak vision carrier level.

This 5.45 MHz i.p. did not produce any perceptible patterning, even on critical pictures such as 'colour bars dipped-in-grey'. At the reference receiving site the quality of the picture and primary sound signals transmitted from Wenvoe were assessed as Grade 5 (excellent).

5.2.2. Performance of the transposers

a) Relative level of the second sound carrier

With the exception of the Mynydd Machen transposer, the relative level of the second sound carrier received at the transposer reference sites was attenuated to below the relative level of −20.3 dB transmitted from Wenvoe. However, in contrast to what might have been expected, the relative attenuation of the second sound carrier did not increase progressively along the transposer chains. For example, looking at Table 3, it may be seen that the relative level (with respect to the peak vision carrier level) of the second sound carrier transmitted from the Brecon transposer was −25.0 dB, but that from the Clyro transposer, which is fed from the Brecon transposer, was −21.8 dB, i.e. an increase in relative level of 3.2 dB.

Overall, the average relative level of the second sound carrier transmitted from the transposers was about −24 dB i.e. about 4 dB lower than that transmitted by Wenvoe.

b) Transmitted eye-heights

The measured eye-heights of the d.p.s.k. signal also failed to show the expected progressive decline along the transposer chain. Thus, although the measured d.p.s.k. eye-height had declined to only 37% when receiving the Abergavenny transposer at its reference site, it had recovered to 48% when receiving the Brecon transposer and 51% when receiving the Clyro transposer, at their respective reference sites.

The average transmitted d.p.s.k. eye-height from the 9 transposers (as assessed from measurements made at the reference sites) was 44.8% and the transmitted d.p.s.k. eye-height from the Pennorth transposer, which is at the end of the tandem chain of five, was assessed as 32%, which is regarded as acceptable at the end of a long chain and where there is a low-power transmitter.

An investigation was made into the causes of the variations in the transmitted d.p.s.k. eye-heights along the transposer chain. It was found that the major contribution to the reduction in the d.p.s.k. eye-height transmitted by some transposers was cross-modulation from the vision signal to the second sound carrier. This is to be expected in a transposer where vision and sound signals are amplified together in a common device. However, no adequate explanation could be found for the observed result that the cross-modulations on the output signals of the Brecon, Clyro, Llyswen, Llanfoist and Crucorney transposers were apparently smaller than those measured on their respective input signals (as assessed by measurements made receiving their respective sources). This phenomenon requires further investigation, but was consistent in its effects thoughout the three-week period of the field-tests.

c) Relative levels of intermodulation products

As was noted in Section 4.2.2., it was difficult to assess the levels of the i.p.s. in the received signals during 4-tone tests because of the masking effects of the harmonics of line-syncs. However, with the exception of the 5.45 MHz i.p., all other i.p.s were assessed to be below −50 dB with respect to peak vision carrier level, which is a relatively good result for a long transposer chain.

The level of the 5.45 MHz i.p. did not vary significantly along the transposer chains and is, therefore, attributable mainly to non-linearity in the sound transmitters at Wenvoe.

No picture patterning attributable to i.p.s was observed when receiving via any of the tranposers investigated in these field-tests.

5.3. Reception impaired by low field-strength

The results of the measurements of the field-strength margin available for successful decoding of the received d.p.s.k. signal, using the procedure described in Section 3.4, are summarised in Fig. 12. The failure point of the d.p.s.k. system was taken to be when the measured bit error-rate reached 5×10^{-3}.*

The results of the measurements at Site 21 have been excluded here because, with the aerial orientated for best picture reception, the d.p.s.k. eye was completely closed. One set of measurements made at site 5 have also been excluded because of instrumentation problems at the transmitter during those measurements.

Of the remaining 42 sets of measurements, 17 relate to reception from Wenvoe directly, and 25 to reception via one or more transposers. Hence the results have been divided accordingly into two sets.

The measured values of field-strengths at the failure point of the d.p.s.k. system are difficult to interpret directly because the field-strength at which this failure point occurs depends upon the overall gain of the u.h.f. aerial system, and the noise figure of the u.h.f. receiving equipment. Therefore, in order to give a firm basis on which to compare results, the following procedure was adopted to arrive at the cumulative frequency distribution curves plotted in Fig. 12:

1) The picture signal-to-r.m.s. unweighted noise ratios were calculated from the measured field-strengths using the formulae given in Appendix 2, and the measured gain and noise factors of the u.h.f. receiving system (also given in Appendix 2) in the measuring vehicle.

2) The cumulative distributions of the picture signal-to-noise ratios at the d.p.s.k. failure points for the two sets of results were then formed to give curves of the percentage of the measurements in which the d.p.s.k. system failed for a picture signal-to-noise ratio less than or equal to the value shown.

3) In order to relate these results to the subjective picture quality at the failure points, the curve relating picture signal-to-r.m.s. unweighted noise ratio to the subjective picture quality, as assessed under laboratory conditions and measured on the CCIR 5-point Quality Scale, was derived from the results given in Reference[25].

4) The relationship between measured field-strength and picture signal-to-noise ratio applicable to a typical domestic u.h.f. receiving system was then calculated for Bands IV and V using the estimated typical overall gain and noise figures given in References[26, 27]. This enabled the two additional co-ordinate axes of field-strengths, applicable to Bands IV and V respectively, to be included together with the line indicating the nominal service area limit.

The average picture signal-to-noise ratios at which the d.p.s.k. system failed when receiving Wenvoe directly was 18.7 dB, and the sample standard deviation was 2.9 dB. The corresponding figures for reception via one or more transposers are an average picture signal-to-noise ratio of 24.6 dB and a sample standard deviation of 4.1 dB.

These differences in the measured sample average values and standard deviations between the two sets of results are largely accounted for by the measured spread of relative attenuations of the second sound carrier when received via transposers, as was described in the previous Section.

The differences between the measured sample averages and the theoretical failure point of an ideal d.p.s.k. system (picture signal-to-noise ratio $\approx$ 12.4 dB) are consistent with the degradations of transmitted eye-height and second sound carrier level noted in the previous Section.

The plotted curves indicate that, for the

* The actual failure point for the digital sound signal in a final system would depend upon the details of the baseband coding used (e.g. the error protection) and may well differ somewhat from the bit error-rate shown as the failure point here.

The measurements made using the error analysis unit indicated that under field-strength-limited reception conditions, the errors occurred essentially randomly in pairs (due to differential coding and decoding) as would be expected for random noise.

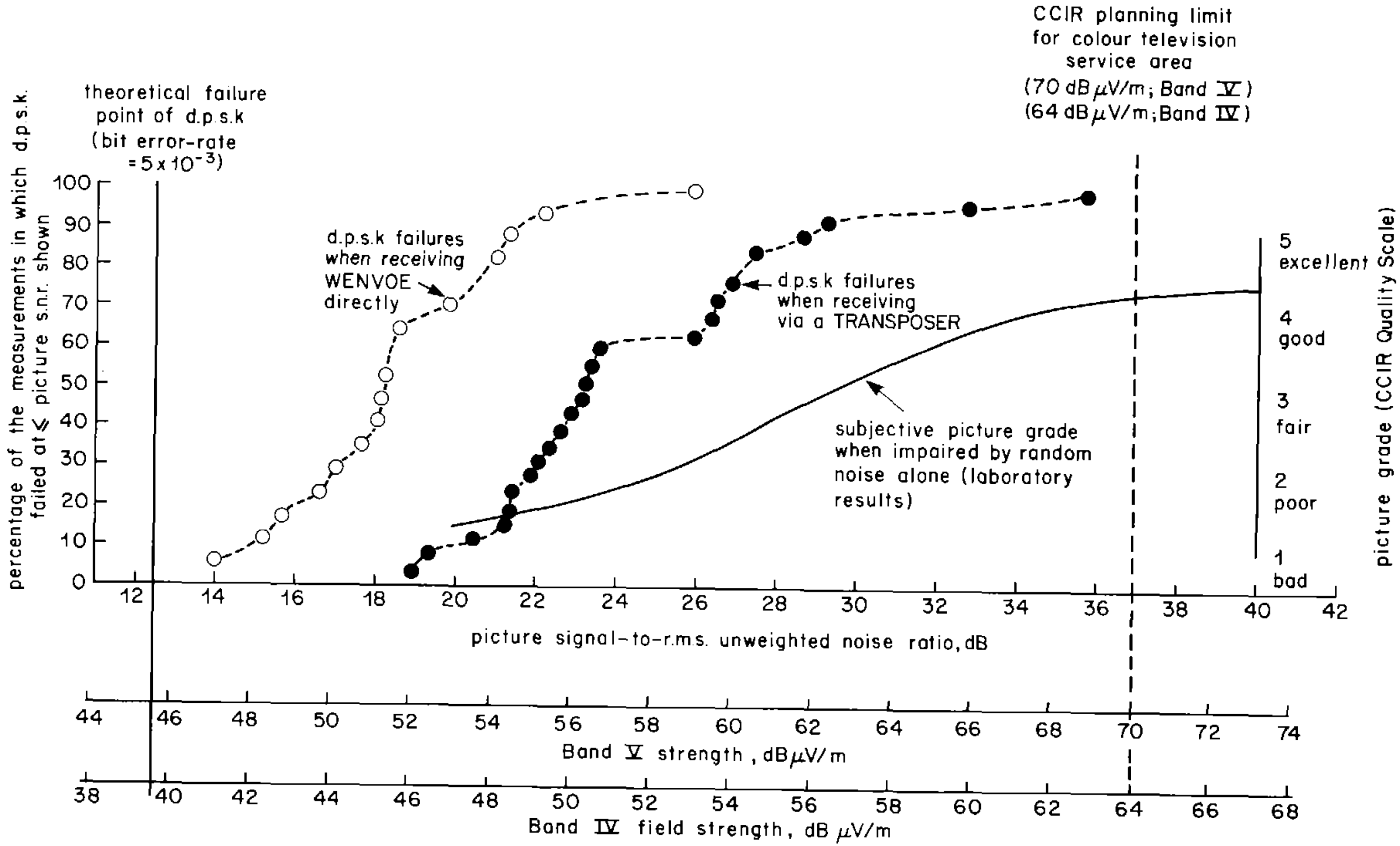


Fig. 12 – Comparison between television performance and 4-phase d.p.s.k. performance for reception impaired by low field-strength.

selection of sites tested:

i) For 90% of the measurements made when receiving signals from Wenvoe directly, the d.p.s.k. system failed at a picture signal-to-noise ratio of 21.5 dB or less, which corresponds to a picture quality of about Grade 1.5 (between bad and poor).

ii) For 90% of measurements made when receiving via transposers, the d.p.s.k. system failed at a picture signal-to-noise ratio of 29 dB or less which corresponds to a picture quality of about Grade 3 (fair).

It is very important not to interpret these results as being representative of all receiving sites. In that respect they are almost certainly over-pessimistic because the proportion of sites with poor reception conditions included in our small sample was deliberately high in order to include the effects of many kinds of impairment. Furthermore, it must be remembered that the sample size is very small and therefore the statistical significance of the results is correspondingly low.

Nevertheless, these results are very encouraging, and clearly indicate that when receiving signals directly from a main station under field-strength-limited reception conditions, the proposed d.p.s.k. system would not, on average, fail before the picture became unacceptably noisy. When receiving signals via a transposer, the corresponding result is less conclusively in favour of the d.p.s.k. system but, even so, the average failure point of the d.p.s.k. system occurs at field-strengths well below the nominal service area limit contours for Bands IV and V.

The f.m. primary sound system is much more rugged than the picture signal under field-strength limited reception conditions, and would, even with the 3 dB reduction of the transmitted primary sound carrier level used in these tests, fail at a picture signal-to-noise ratio of 10 dB or less, i.e. about 3 dB or more below the theoretical failure point of the d.p.s.k. system*.

Teletext decoders operating under field-strength-limited conditions fail for a picture signal-to-noise ratio in the region 15 to 20 dB, depending upon the criterion used to assess failure. Thus, the proposed d.p.s.k. system and teletext would be expected to fail at similar points under field-strength-limited reception conditions.

It is interesting to note that the results obtained when receiving Wenvoe directly include sites where the picture signal-to-noise ratio at the failure point of the d.p.s.k. system was up to 4 dB lower than that measured at the reference site. This indicates that, at those sites, local reception conditions may have been such as to effectively increase the level of the second sound carrier relative to the vision carrier. This hypothesis will be confirmed by the results presented in the next Section.

*These are measured results for an inter-carrier sound receiver. If a receiver with independent sound i.f. stages were used, then the failure point of the f.m. primary sound system would be expected to be lower by up to about 20 dB.

5.4. Reception impaired by multipath propagation

Two effects due to multipath propagation may be identified:

1) Variation of sound-to-vision carrier level ratios. Echo-signals due to multipath propagation can, according to their precise delay, either reinforce or partially cancel components at selected frequencies within the overall bandwidth of the received signals. Thus, particular echoes can effect the received levels of the vision carrier or primary or secondary sound carriers.

2) Variation of the received eye-height of the d.p.s.k. signal due to intersymbol interference produced by the echo-signals. The echo-signals may be thought of as being analogous to the signals from the taps in a transversal filter. According to their precise delays and amplitudes these echo-signals will reduce, or in some cases increase, the eye-height of the received d.p.s.k. signal[28].

5.4.1. Variations of sound-to-vision carrier level ratios

The measured levels of the received primary and secondary sound carriers, measured relative to the received vision carrier level, are presented for 9 selected sites as a bar-chart, Fig. 13. Results are presented here only for those sites where the measured levels of the received primary and/or secondary sound carriers relative to the received vision carrier level, differed significantly from the relative levels received at the reference sites.

It may be seen from Fig. 13, that the measured range of variation of the relative level of the received second sound carrier is +3.8 dB to

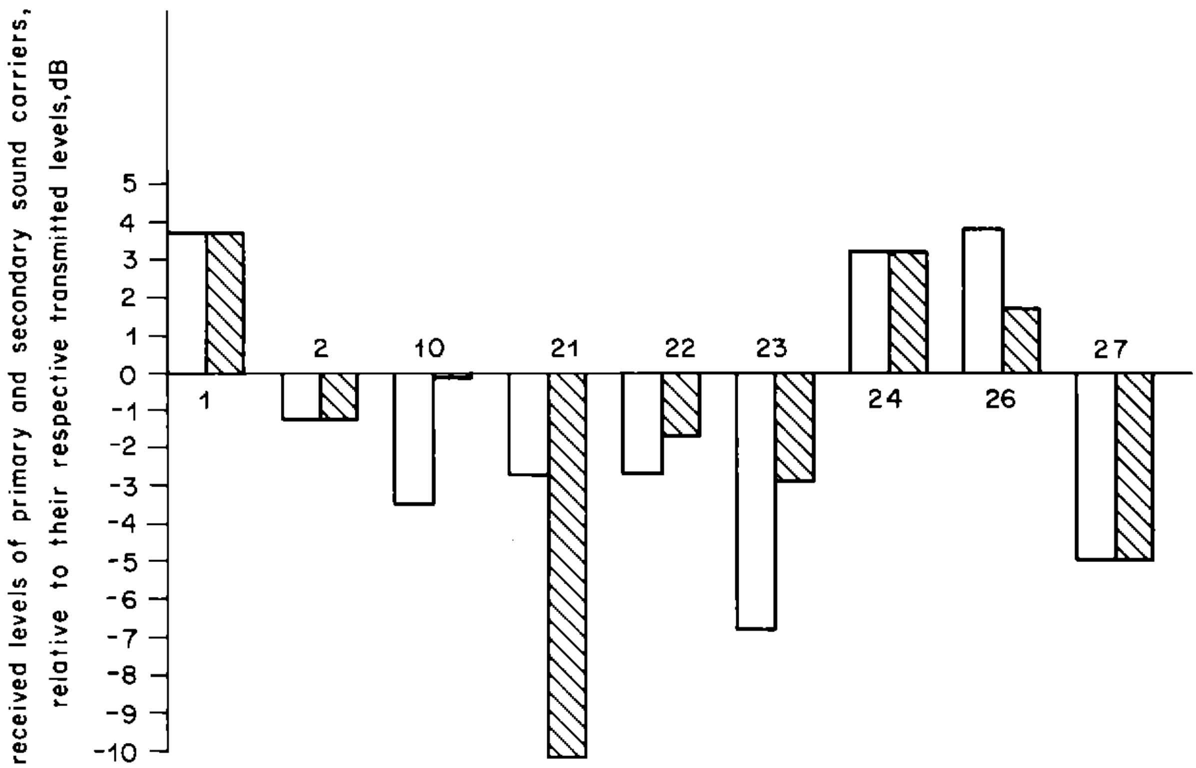


Fig. 13 — Bar-chart showing measured levels of primary and secondary sound carriers received at selected sites relative to their transmitted levels.

−10 dB, and that of the first sound carrier +3.8 dB to −6 dB. Similar results were obtained during the earlier tests of the analogue two-carrier system from the Crystal Palace transmitter in London[8]. At site 1, for example, the levels of the primary and secondary sound signals are both increased by 3.8 dB relative to the received level of the vision carrier. This suggests that at this site the vision carrier was partially cancelled by an echo signal. At site 21 a very strong echo caused almost complete cancellation of the second sound carrier.

The enhanced second sound carrier-to-vision carrier ratios measured at sites 1, 24, and 26, explain the reduced picture signal-to-noise ratios needed for successful d.p.s.k. reception at these sites, as was discussed in the previous Section.

5.4.2. Distributions of d.p.s.k. eye-height

The results of eye-height measurements of the demodulated d.p.s.k. signal at 42 receiving sites are presented as cumulative frequency distributions in Fig. 14. The results obtained at site 26 have been excluded because the received field-strength there was too low to obtain an eye-height reading. The results obtained receiving Wenvoe directly at site 21 have also been excluded because, due to severe ghosting, the received picture signal was assessed as grade 1 (bad) for all aerial

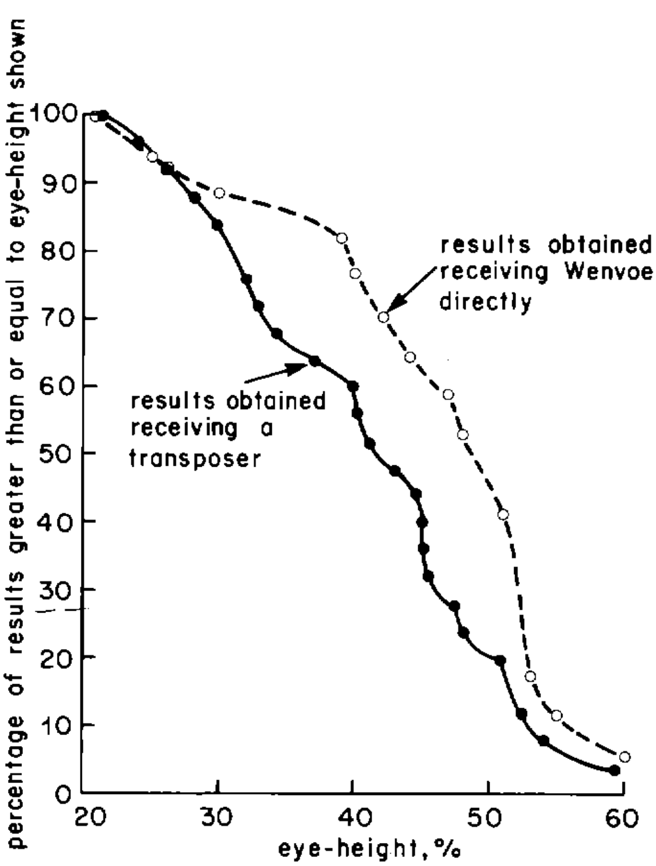


Fig. 14 — Cumulative frequency curves for eye-height.

orientations and a satisfactory alternative service is available. At this site, an eye-height of 30% could be obtained when receiving Wenvoe directly by slight re-orientation of the receiving aerial away from that chosen to give the best picture.

Of the remaining 42 sets of measurements, 17 relate to reception from Wenvoe directly, and 25 to reception via one or more transposer. Hence the results have been divided accordingly into two sets.

The average measured d.p.s.k. eye-height when receiving Wenvoe directly was 44.5% and the sample standard deviation is 10.7%. The average measured d.p.s.k. eye-height when receiving signals via one or more transposer is 40% and the sample standard deviation is 10.3%.

From the cumulative frequency distribution curves as a function of d.p.s.k. eye-height, it may be seen that:

i) For 90% of the measurements made when receiving signals directly from Wenvoe, the received d.p.s.k. eye-height was greater than or equal to about 30%.

ii) For 90% of the measurements made when receiving signals via a transposer, the received d.p.s.k. eye-height was greater than or equal to about 28%.

It is interesting to note that multipath propagation actually improved the received d.p.s.k. eye-height at several sites. For example, at site 1 an eye-height of 60% was measured when receiving signals from Wenvoe directly (compared with the estimated transmitted d.p.s.k. eye-height of 52%). At this site, strong short-delay ($< 3\mu s$) ghosts were observed on the received picture.

When receiving signals from Wenvoe directly, the worst received d.p.s.k. eye-height (excluding the results from site 21) was about 20%, which was measured at site 26. The quality of the best picture obtainable at this site was assessed as Grade 1 (bad) and was full of large amplitude long-delay ghosts.

The worst received d.p.s.k. eye-height when receiving signals via transposers was about 21%, which was measured at site 5 when receiving signals from the Pennorth transposer (c.f. an estimated transmitted eye-height of 32% from this transposer). Here there was no perceptible impairment to the received picture, but the received teletext eye-height at site 5 was measured to be 27% as compared with an estimated transmitted teletext eye-height of 60% for this transposer.

Overall, therefore, these measurements indicate that the proposed d.p.s.k. system is adequately rugged against the effects of multipath propagation.

5.4.3. Relationship between d.p.s.k. eye-height and teletext eye-height at selected sites

The measured teletext eye-heights and d.p.s.k. eye-heights for 15 selected representative sites are shown in Fig. 15. Although there is clearly little correlation between the received teletext and d.p.s.k. eye-heights, it is important to note that at sites 26 and 2, the teletext system failed, but the d.p.s.k. eye-heights were 20% and 48% respectively. Indeed, it was generally observed that under reception conditions impaired by multipath propagation, the teletext system was significantly less rugged than the proposed d.p.s.k. system. This is as would be expected from comparison of their relative bandwidths.

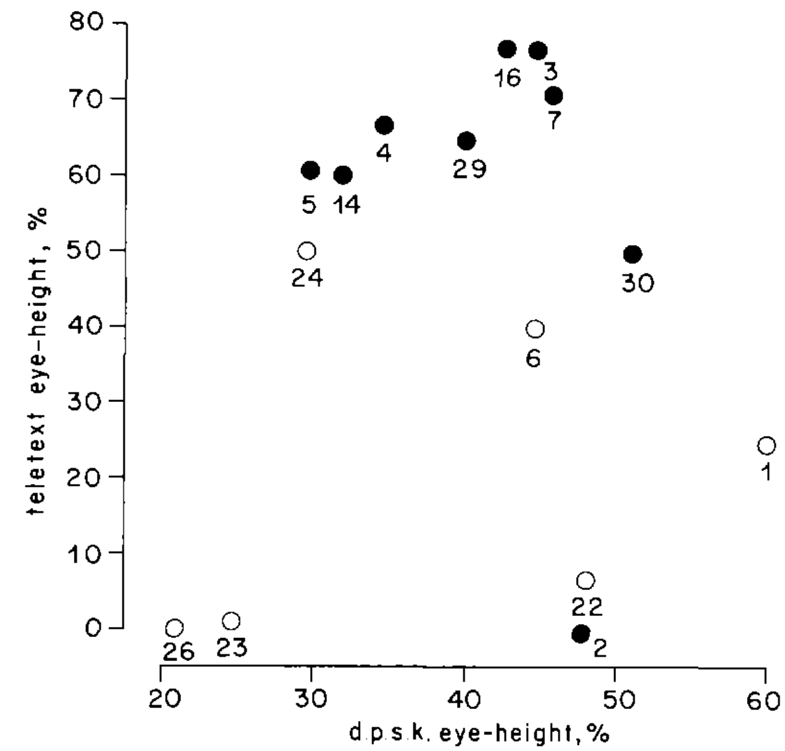
5.5. Reception impaired by ignition interference

Although no formal tests were conducted to investigate the effects of ignition or other man-made interference on the proposed d.p.s.k. system, observations of the effects of interference from the ignition system of the measuring vehicle indicated that ignition interference is unlikely to be troublesome to the proposed d.p.s.k. system.

5.6. Overall results and discussion

Overall, the experimental d.p.s.k. system proved to be acceptably rugged against impairment to reception due to the effects of distortions in a long chain of transposers, low field-strength, multipath, propagation, and ignition interference, or indeed any of these impairments in combination.

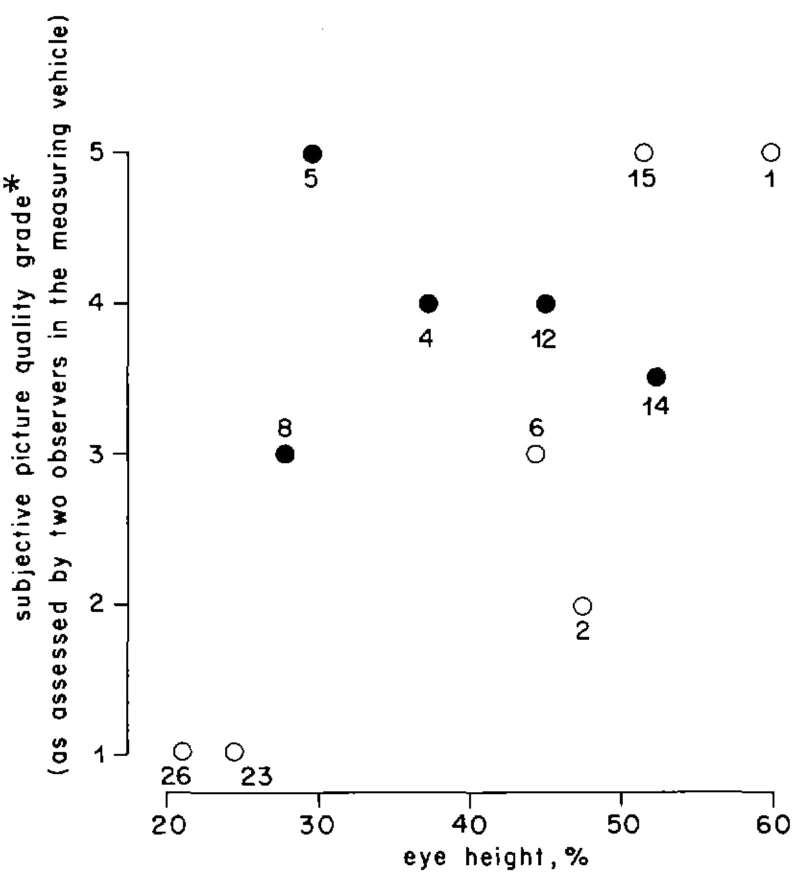
In an attempt to correlate the performance of the proposed d.p.s.k. system with that of the television system for reception under all of these various impairments, the measured d.p.s.k. eye-heights and approximate picture grades for 11 selected representative sites are plotted in Fig. 16. It may be seen that there is very little correlation between these two sets of results. It must, however, be remembered that the measured range



○ measured at site *n* receiving Wenvoe
n directly

● measured at site *n* receiving via a
n transposer

Fig. 15 – Teletext eye-height and d.p.s.k. eye-height at selected sites.



○ measured at site *n* receiving Wenvoe
n directly

● measured at site *n* receiving via a
n transposer

Fig. 16 – Subjective grade and d.p.s.k. eye-height at selected sites.

*subjective assessments of picture grades were made by two observers under difficult conditions in the measuring vehicle and can only be taken as approximate.

of impairment to the d.p.s.k. signal is relatively small, and (with the exception of site 21) the proposed system could have provided a service at all of the test-sites. In contrast, the measured range of picture quality was large, and at sites 23 and 26 the picture was unusable.

Furthermore, in interpreting the results of these field-tests it is important to bear in mind the following factors:

i) As was noted earlier, the selected test-sites deliberately included a high proportion with poor reception conditions.

ii) No attempt was made to optimise the performance of the transposers to accommodate the proposed d.p.s.k. system; simple adjustments to correct the relative transmitted level of the second sound carrier would be worthwhile and would yield a significant improvement in the results obtained at sites receiving signals via transposers.

iii) The transmitted d.p.s.k. eye-height from Wenvoe could probably have been improved by the use of group delay pre-correction networks in the d.p.s.k. signal feels to the sound transmitters.

iv) Approximately 95% of viewers are served directly from main stations and only about 5% are served via transposers; an even smaller percentage of viewers are served by long chains of transposers.

Thus overall, under all the measured reception impairments, it is concluded that the proposed d.p.s.k. system is at least as rugged as the television system. However, the adaption of the transmitter network to accommodate a digital signal could be done in such a way as to provide an enhanced margin for operating conditions.

6. Conclusions and recommendations for further work

An experimental digital system to carry two high quality sound channels with the existing terrestrial u.h.f. television transmission System I has been devised. This experimental system uses a 4-phase d.p.s.k. modulated second sound carrier spaced at about 6.55 MHz above the vision carrier, next to the existing analogue sound carrier at 6 MHz. The proposed amplitudes of the sound carriers are 10 dB and 20 dB below the vision signal for the analogue and digital sound carriers respectively. Within the spectrum space available, a data-rate of about 700 kbit/s can be provided, which is capable of carrying a stereo sound pair of channels (or two independent sound channels). A few kbit/s of spare data capacity would also be available to carry supplementary control signals.

Laboratory tests of the effects of adjacent-channel interference indicated that with the above parameters for the digital system, the existing planning protection ratios would adequately safeguard the vision signal in the upper adjacent channel from interference by the digitally modulated second sound carrier, and vice-versa.

The quality of sound offered by such a digital system would be comparable with that offered by digital audio discs.

During October 1983, the BBC-2 transmitter at Wenvoe, and its associated rebroadcast relay stations, was used out of normal programme hours, to make over-air tests of the ruggedness of the experimental system.

These tests showed that the experimental digital system could be transmitted from a main station and would travel acceptably through the chains of up to five transposers which are needed to serve the Welsh Valleys. Extensive field measurements also established that the experimental digital system is acceptably rugged against impaired reception due to low field-strength, multipath propagation, and ignition interference, or any of these impairments in combination. Indeed, preliminary indications are that the service area for satisfactory reception of the digital sound signals would be equal to or greater than the service area limits for satisfactory colour television reception.

The most urgent task in the further development of the proposed system is to confirm its compatibility with the widest range of domestic receivers. It is therefore intended that a public field-trial, similar to that conducted in October 1982 with the analogue two-carrier system, be performed from the Crystal Palace transmitter.

There remains some flexibility in the choice of certain elements of the specification of the proposed digital system, particularly in relation to possible reduction of receiver costs. Some compromises in performance may also be justified if substantial advantages from economy of scale can be obtained by using the same technology as is used in other consumer products, e.g. digital audio discs or DBS television.

It is therefore intended to discuss these issues with other interested parties in order to refine the specification, especially in regard to the details of the baseband coding of the digitised sound signals.

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8. References

1. EDWARDSON, S.M. 1982. Stereophonic and two-channel sound in terrestrial television broadcasting, IBC 1982. *IEE* Conference Publication No. 220, pp 276-279.

2. CCIR. 1978. Recommendations and Reports of the CCIR, 1978. Volume X, Broadcasting Service (Sound), Recommendation 450. XIVth Plenary Assembly, Kyoto, 1978.

3. CCIR. 1978. Recommendations and Reports of the CCIR, 1978. Volume X, Broadcasting Service (Sound), Report 795. XIVth Plenary Assembly, Kyoto, 1978.

4. NUMAGUCHI, Y. *and* HARADA, S. 1981. Multichannel sound system for television broadcasting. *IEEE* Transactions on Consumer Electronics, Vol. CE-27, No. 3, August 1981, pp 366-371.

5. DINSEL, S. 1980. Stereophonic sound and two languages in TV, the double-sound carrier method. International Broadcasting Conference 1980. *IEE* Conference Publication No. 191, pp 207-211.

6. HOPF, H. 1981. Multi-channel sound transmission methods (Mehrkanalton-Ubertragunstechnik). ZDF Schriftenreihe, Heft 27, Mainz, August 1981.

7. DINSEL, S. 1983. Two-carrier system in Germany since 1981. *IEE* Colloquium on Dual Channel TV Sound Terrestrial Broadcasting and Reception, April 1983. *IEE* Digest No. 1983/29, pp 1/1-1/5.

8. JONES, A.H. 1983. The two-carrier method for dual channel TV sound: over-air tests in the UK. *IEE* Coloquium on Dual Channel TV Sound Terrestrial Broadcasting and Reception, April, 1983. *IEE* Digest No. 1983/39, pp 2/1-2/4.

9. EATON, J.L. *and* HARVEY, R.V. 1980. A two-channel sound system for television. International Broadcasting Conference 1980. *IEE* Conference Publication No. 191, pp 212-215.

10. EBU. 1983. Television standard for 625-line 12 GHz satellite broadcasting. SPB 284.

11. OSBORNE, D.W. *and* CROLL, M.G. 1973. Digital sound signals: bit-rate reduction using an experimental digital compandor. BBC Research Department Report No. 1973/41.

12. GILCHRIST, N.H.C. *and* REID, D.F. 1977. Experimental 704 kbit/s multiplex equipment for two 15 kHz sound channels. BBC Research Department Report No. 1977/38.

13. BENNETT, W.R. *and* DAVEY, J.R. 1965. Data transmission. New York, McGraw Hill, 1965.

14. GRONEMEYER, S.A. *and* McBRIDE, A.L. 1976. MSK and offset QPSK modulation. *IEEE* Transactions on Communications, Vol. COM-25, No. 4, April 1977, pp 809 - 819.

15. AMOROSO, F. *and* KIVETT, J.A. 1977. Simplified MSK signalling technique. *IEEE* Transactions on Communications, Vol. COM-25, No. 4, April 1977, pp 433-441.

16. WHYTHE, D.J. 1981. An experimental 4-phase d.p.s.k. system to transmit two high-quality digital sound signals. EBU Review-Technical, No. 185, February 1981, pp 2-12.

17. DENYER, M.C., GILCHRIST, N.H.C. KALLAWAY, M.J. *and* PALMER, R.J. 1979. Digital radio links for stereophonic outside broadcasts. BBC Engineering Division Report RD 1979/2.

18. EATON, J.L. *and* EDWARDSON, S.M. 1978. Digital sound broadcasting tests in Band I. International Broadcasting Conference 1978. *IEE* Conference Publication No. 166, pp 317-320.

19. KALLAWAY, M.J. 1976. An experimental 4-phase differential-phase-shift-keying system to carry two high-quality digital sound signals. BBC Research Department Report No. 1976/20.

20. CCIR. 1978. Recommendations and Reports of the CCIR, 1978. Volume XI, Broadcasting Service (Television), Recommendation 418. XIVth Plenary Assembly, Kyoto, 1978.

21. MAHADEVA, W.A. 1977. A 4-phase differential-phase-shift-keying stereo sound system: carrier recovery methods. BBC Research Department Report No. 1977/1.

22. HARMAN, M.W. *and* FOX, J.A. 1976. A u.h.f. programmable digital field strength measuring receiver. BBC Research Department Report No. 1976/27.

23. CROLL, M.G. 1977. Ceefax: measurement techniques. BBC Research Department Report No. 1977/6.

24. CCIR, 1978. Recommendations and Reports of the CCIR, 1978. Volume XI, Broadcasting Service (Television), Recommendation 417-2. XIVth Plenary Assembly, Kyoto, 1978.

25. ALLNATT, J.W. *and* PROSSER, R.D. 1966. Subjective quality of colour-television pictures impaired by random noise. Proceedings of the *IEE*, 1966, Vol. 113, No. 4, pp 551-557.

26. BBC ENGINEERING INFORMATION, 1982. Good TV reception - the professional way. Information Sheet *2107(1) 8204*, Engineering Information Department, BBC, Broadcasting House, London.

27. BBC ENGINEERING INFORMATION, 1983. 625-line television reception. Information Sheet *4006(8) 835*, Engineering Information Department, BBC, Broadcasting House, London.

28. KALLAWAY, M.J. 1978. An experimental 4-phase d.p.s.k. stereo sound system: the effect of multipath propagation. BBC Research Department Report No. 1978/15.

29. BBC RESEARCH DEPARTMENT TECHNICAL HANDBOOK. The calibration of VHF/UHF field strength measuring equipment. Internal document.

30. OSBORNE, B.W. 1977. Television signal-to-noise ratio before and after demodulation. The Radio and Electronic Engineer, 47, 12, December 1977, pp 555-561.

Appendix 1

Details of the u.h.f. transmitting stations used in the field-tests.

Station	Source of Signals	Channel for BBC-2 transmissions	Offset*	Polarisation	Max. e.r.p. (kW)
Wenvoe	—	51	0	H	500
Ebbw Vale	Wenvoe	62	$+\frac{5}{3}f_L$	V	0.5
Abergavenny	Ebbw Vale	45	$+\frac{5}{3}f_L$	V	1
Brecon	Abergavenny	64	$-\frac{5}{3}f_L$	V	1
Clyro	Brecon	44	$-\frac{5}{3}f_L$	V	0.16
Pennorth	Clyro	26	0	V	0.05
Mynydd Machen	Wenvoe	26	$+\frac{5}{3}f_L$	V	2
Llanfoist	Abergavenny	63	0	V	0.018
Crucorney	Llanfoist	27	$-\frac{5}{3}f_L$	V	0.011
Llyswen	Brecon	27	0	V	0.03

*The frequency offset of the transmitted vision carrier is expressed as a multiple of television line-frequency, f_L (15.625 kHz).

Appendix 2

Relationships between field-strength, picture signal-to-noise ratio, and error-rate in the 4 phase d.p.s.k. system

A2-1 Calculation of received picture signal-to-r.m.s. unweighted noise ratio from measured field-strength

If a half-wave dipole, whose radiation resistance is R_A ohms, is terminated in a load resistance of R_L ohms, and is placed in an electric field of strength E volts/metre, then the potential difference, V_L, developed across the load resistance may be shown[29] to be given by:

$$V_L = E.\ \frac{\lambda}{\pi} \cdot \frac{R_L}{R_A + R_L} \quad \text{volts} \tag{1}$$

where λ = wavelength of the received signal in metres.

Expressing both V_L and E in decibels relative to 1μVgives:

$$V_{L(\mathrm{dB}\mu\mathrm{V})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} + 20\log\frac{\lambda}{\pi} - 20\log\left(1 + \frac{R_A}{R_L}\right) \tag{2}$$

If the load is matched to the aerial, i.e. $R_L = R_A$,

then:

$$V_{L(\mathrm{dB}\mu\mathrm{V})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} + 20\log\frac{\lambda}{\pi} - 6 \tag{3}$$

or the received carrier power dissipated in the load R_L is given by:

$$C_{(\mathrm{dBpW})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} + 20\log\frac{\lambda}{\pi} - 6 - 10\log R_A \tag{4}$$

For a practical u.h.f. aerial system two further factors must be included:

G_A = aerial gain relative to a half-wave dipole (dB).

f_c = loss in the feeder cable between the aerial and the input to the u.h.f. receiver (dB).

Hence:

$$C_{(\mathrm{dBpW})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} + 20\log\frac{\lambda}{\pi} - 6 - 10\log R_A + G_A - f_c \tag{5}$$

Measured values for R_A, G_A and f_c in the aerial system of the measuring vehicle used in the field-tests are given, for the various receiving frequencies, in Table 4.

Hence, for example, when receiving Channel 51 (Wenvoe):

$$C_{(\mathrm{dBpW})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} - 17.4 - 6 - 17.0 + 8.2 - 10.2$$

$$= E_{(\mathrm{dB}\mu\mathrm{V/m})} - 42.4 \tag{6}$$

The effective thermal noise power developed across the receiver input is given by:

$$N_{(\mathrm{dBpW})} = 10\log(k\mathrm{TB}) + F \tag{7}$$

TABLE 4

UHF field-strength calibration data for the aerial system used in the measuring vehicle

Channel	Vision Carrier frequency* (MHz)	Stations transmitting in this channel and investigated in these field-tests	$20 \log(\frac{\lambda}{\pi})$ (dB)	Gain of air-spaced log-periodic aerial G_A (dB)	Measured feeder and other losses ** f_c (dB)	Aerial radiation resistance R_A (ohms)	UHF pre-amplifier noise figure (dB)
26	511.25	Pennorth Mynydd Machen	−14.6	8.1	8.1		
27	519.25	Crucorney Llyswen	−14.7	8.1	8.1		
44	655.25	Clyro	−16.7	8.2	9.3		
45	663.25	Abergavenny	−16.8	8.2	9.0	50	9
51	711.25	Wenvoe	−17.4	8.2	10.2		
62	799.25	Ebbw Vale	−18.5	8.1	9.7		
63	807.25	Llanfoist	−18.5	8.1	9.6		
64	815.25	Brecon	−18.6	8.0	9.7		

*Offsets have been ignored

**includes a 3 dB directional coupler

where k = Boltzmann's constant = 1.38×10^{-23} J/ °K

T = noise temperature of the aerial = 290 °K

B = bandwidth of the receiver = 5.05 MHz for video

F = receiver noise figure (dB)

For the u.h.f. pre-amplifier used in the measuring vehicle the noise figure, F, was 9 dB. Thus, the effective thermal noise power in the video signal bandwidth is given by:

$$N_{(\mathrm{dBpW})} = -16.9 + 9$$

$$= -7.9 \text{ dBpW} \tag{8}$$

Hence, from Equations 5 and 8, the vision carrier-to-noise ratio is given by:

$$C_{(\mathrm{dBpW})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} + 20\log \frac{\lambda}{\pi} - 6 - 10\log R_A + G_A - f_c + 7.94$$

(where, of course, E is the measured field-strength of the vision carrier)

e.g., for reception of signals in Channel 51:

$$C/_N \text{ (vision)} = E_{(\mathrm{dB}\mu\mathrm{V/m})} - 42.4 + 7.9$$

$$= E_{(\mathrm{dB}\mu\mathrm{V/m})} - 34.5 \text{ dB} \tag{9}$$

Now, the picture signal-to-r.m.s. unweighted noise ratio, S/N, is related to the received vision carrier-to-noise ratio as follows:

$S/_N$ (vision) = $C/_N$ (vision)

+ 3 dB (conversion from r.m.s. carrier level to peak carrier level)

−5 dB (conversion from peak carrier level to r.m.s. picture signal level)

−3 dB (allowance for vestigial sideband filtering of the received signal prior to detection[30])

$$= C/_N \text{ (vision)} - 5 \text{ dB} \tag{10}$$

Hence, for Channel 51:

$$S/_N \text{ (vision)} = E_{(\mathrm{dB}\mu\mathrm{V/m})} - 39.5 \text{ dB} \tag{11}$$

Measurements made with the receiving equipment used in the measuring vehicle in these field-tests gave, for reception on Channel 51, that a measured field-strength of 60 dBμV/m resulted in a measured picture signal-to-r.m.s. unweighted noise ratio of 20.5 dB, which shows excellent agreement with the theoretical relationship given in Equation 11 above.

A2-2 Relationship between field-strength and picture signal-to-noise ratio for a typical domestic installation

For a typical domestic installation we assume that[26,27]:

Aerial gain relative to a half-wave dipole = 10 dB

Feeder and other losses = 3 dB

Receiver noise figure = 10 dB

and we note that the aerial system impedance = 75Ω (c.f. the 50Ω aerial system in the measuring vehicle).

Thus, substituting into Equation 4 above for Channel 51 gives, for a typical domestic installation, the received carrier power, C, at the receiver input is given by:

$$C_{(\mathrm{dBpW})} = E_{(\mathrm{dB}\mu\mathrm{V/m})} - 35.0$$

(where, as before, E is the measured field-strength in dB relative to 1μV/m).

Substituting into Equation 7 above, the effective noise power at the receiver input is given by:

$$N_{(\mathrm{dBpW})} = -16.9 + 10$$

$$= -6.9 \text{ dBpW}$$

$$\therefore \quad C/_{N}\text{ (vision)} = E_{(\mathrm{dB}\mu\mathrm{V/m})} - 28.1$$

and from Equation 10:

$$S/_{N}\text{ (vision)} = C/_{N}\text{ (vision)} - 5\text{ dB}$$

Hence, in a typical domestic installation for Band V reception

$$S/_{N}\text{ (vision)} = E - 33.1\text{ dB} \qquad (12)$$

For example, a measured field-strength of 70 dBμV/m in Band V gives, according to Equation 12 above, a picture signal-to-r.m.s. unweighted noise ratio in a typical domestic receiver of 36.9 dB.

For reception in Band IV, it is usually stated that, because of larger values of $\frac{\lambda}{\pi}$ and smaller feeder losses, etc., a field-strength 6 dB less than that needed in Band V is required to achieve a given picture signal-to-noise ratio. For example, 64 dBμV/m) in Band IV may be taken to produce the same picture signal-to-noise ratio as a field-strength of 70 dBμV/m in Band V.

A2-3 Relationship between picture signal-to-r.m.s. unweighted noise ratio and theoretical error-rate in the experimental 4-phase d.p.s.k. system

The r.m.s. level of the transmitted 4-phase d.p.s.k. carrier relative to the r.m.s. level of the vision carrier is, in the experimental system, −20 dB.

Hence, the received d.p.s.k. carrier power C (d.p.s.k.) is given by:

$$C\text{ (d.p.s.k.)} = C\text{ (vision)} - 20\text{ dB} \qquad (13)$$

The noise bandwidth of the d.p.s.k. system may be taken to be a bandwidth numerically equal to the bit-rate, i.e., 704 kHz in the experimental system. Thus the effective thermal noise power in this bandwidth is given by:

$$\begin{aligned} N\text{(d.p.s.k.)} &= N\text{(vision)} - 10\log(0.704/5.05) \\ &= N\text{ (vision)} - 8.6\text{ dB} \end{aligned} \qquad (14)$$

Hence, from Equations 13 and 14:

$$S/_{N}\text{ (d.p.s.k.)} = C/_{N}\text{ (vision)} - 11.4\text{ dB}$$

and Equation 10 gives:

$$S/_N \text{ (vision)} = C/_N \text{ (vision)} - 5 \text{ dB}$$

$$\therefore \quad S/_N \text{ (d.p.s.k.)} = S/_N \text{ (vision)} - 6.4 \text{ dB} \qquad (15)$$

For example, if $S/_N$ (vision) = 12.4 dB then:

$$S/_N \text{ (d.p.s.k.)} = 12.4 - 6.4$$

$$= 6 \text{ dB}$$

And from the curve of Fig. 6, for an ideal 4-phase d.p.s.k. system, a carrier-to-noise ratio of 6 dB will yield an error-rate of 5×10^{-3}.

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